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HUMAN RELATIONSHIPS IN FUTURE MINERAL PROCUREMENT [1]

D. M. DAVIDSON

ABSTRACT

A vital problem facing the free world of today is procuring adequate mineral supplies to meet the demands of an ever expanding economy. Canada's needs are increasing by leaps and bounds, while the United States, with 10 percent of the free world population, uses 50 percent of the free world's minerals. By 1975 the consumption in North America will be twice that of today's with half of the required minerals coming from abroad. A healthy North American economy is prerequisite to the welfare of the free world either in peace or in war; thus, the problem becomes one of efficient yet equitable distribution.

Geological science and new techniques alone are not adequate to meet this demand. It is believed that the most important elements for success are in the development of satisfactory human relationships. In the endeavor which lies ahead, attitudes will be more important than techniques and people more important than rocks.

A system of education is advocated for all those having to do with mineral procurement abroad to the end that they will realize the importance of building good will and faith in those with whom they deal. Only thus can they establish that right relationship and confidence by which we may be assured of those long-term commitments for minerals which are essential for the demands of our expanding economy, upon which is dependent the welfare of the entire free world.

A VITAL problem facing the coming generation is the procurement of adequate mineral supplies for the free world. Canada's needs are increasing by leaps and bounds, while the United States, alone, having only 10 percent of the free world population, uses over 50 percent of its minerals. In all likelihood, by 1975, we in North America shall be consuming at a rate double that of the present day, and a substantial percentage of these minerals by that time will have to be procured from abroad. The other free nations, too, in the years ahead will have expanding mineral requirements as their national economy expands so that the problem becomes one of efficient yet equitable distribution.

[1] Presidential address before Society of Economic Geologists, Toronto Meeting, November, 1953.

One obvious aspect is that in meeting the apparently insatiable demands for minerals on the part of the free world, we in North America must be assured of an adequate supply either in war or in peace. This stems from the supreme importance of our high productive capacity. Wars are won or lost largely on the ability to produce the tools for war. On the other hand, in peace time the economic health of the entire free world is largely dependent on that of North America. Thus, if a breakdown occurs in our production, the entire free world suffers.

Scientific techniques and new inventions are not in themselves adequate to meet this situation. The vital element is sympathetic understanding in the human relationships involved. One of the great anomalies of our time, in fact, is the disparity that exists between the advanced state of knowledge in our material sciences as against our inadequate knowledge of man himself. In this complex world, the paramount problem is finding a common ground and building on it mutual faith and good will.

In appraising the situation in the United States, it has long been obvious that finding new ore bodies is no longer a matter of simple search. The ore bodies that occurred at the surface have long since been found and exploited. Gone are the days when a bearded prospector, accompanied by a burro laden with prospecting equipment, could traverse our wilderness and unearth a bonanza which in turn could be quickly exploited to produce vast mineral wealth. In place of this romantic picture, consider the complexities of modern prospecting for the ore bodies that lie concealed at depth. Nowadays our scientists begin the search with an idea. Studies are made of districts, these studies culminating in a recommendation as to where and how to go about prospecting. This study is a matter of teamwork on the part of several men, all of whom contribute. This is the first link in the important chain of modern-day exploration. Each link is of equal importance and a breakdown anywhere along the chain results in failure. The second link is the matter of selling the idea and recommendations to the principals involved who have to finance the exploration. Scientific techniques are not involved here; rather, success depends on the knowledge of how to influence people. The third link in the chain is that of acquiring sufficient land in which to have elbow room, so to speak, in order to test the original idea. Here again is involved the matter of the establishment of proper human relationships.

Thereafter, the pattern runs approximately as follows: The area will be photographed and the photographic prints used as base maps for teams of specially trained geologists who will carry on detailed field mapping. Concurrently, these photographs will be studied by experts in photogeology, who will coordinate their studies and cooperate with the field parties. In many cases, teams of geophysicists will test the district by various means, and, in the case of buried ore bodies, geochemical means of prospecting are frequently employed. Thereafter follows the coordination of all the data adduced by the several scientific teams.

In view of the complexities of the chain work of modern prospecting, it is not surprising that a vital necessity in each link of the enterprise is the development of the right human relationships not only among members of each indi-

vidual team, but in the overall coordination when the final data are put together. The production of the first atomic bomb is a prime illustration of the successful end of a complex scientific enterprise. The scientists engaged in this joint effort freely concede that they were successful largely because these men were welded together in spirit and were selflessly devoted to the achievement of one all-important objective. It was a case in which the human spirit counted more than the human intellect.

In line with the view that people are the most important elements in the search for and procurement of more minerals, there are three trends now current in the mining world which deserve attention. First, is the matter of the increasing size of mining companies. It is a truism to say that the big companies are getting larger and the small companies are becoming fewer. On balance, this may prove beneficial to the industry as a whole provided that those who guide the destinies of these large companies have the imagination and daring adequate to ensure an increase in mineral inventory, not by purchase, but by means of long-range and adventurous exploration.

Equally important, they must be imbued with the perspicacity and the vision to realize that their technical departments have a thorough grounding in the fine art of human relationships. Large mining concerns these days may be staffed with over a hundred geologists. On these men rests the burden of responsibility of seeing to it that our mineral inventory is adequate. Never have our geologists been better trained in techniques than they are today. We now have dozens of first-grade schools in North America turning out highly qualified men insofar as science is concerned, but, unfortunately, many of these men are not well-rounded. They have scientific knowledge, but too little knowledge of how to handle themselves in their relationship with their fellow men. Those of us who have been engaged in the search for minerals for any length of time have, I think, been impressed with the fact that many of our graduates are immature, especially in inter-personal relationships. This applies not only to graduates; it is also true of many who have gone on to post-graduate study and to higher degrees. It is important, then, for us to insure that our exploration geologists are as adequately trained in handling people as they are in wielding the geological hammer, a thought which should be taken to heart by the executives of large mining companies.

Touching on the matter of people, it is pertinent to appraise the current situation of the independent professional geologist. The true consulting geologist has in the past contributed greatly not only to our knowledge of ore deposits, but to the actual enhancement of our ore reserves. This stems from the fact that the best geologist is a hungry geologist. Hungry not only for material welfare but, as well, for professional esteem and the opportunity for self-expression. There can be no quibble about the fact that a consultant is more hungry than his colleague who is sheltered in the security of a permanent job and looks forward to a pension. His imagination will be bolder and freer, the challenge to him is greater and he will thus often respond in higher manner to this challenge than his permanently employed counterpart. The history of our profession speaks for itself in this regard.

A glance at the status of the consultant today is not reassuring. He is

beset by crippling taxation and relentless competition. Today, under present tax rates, it is difficult, if not impossible, for a consultant or a firm to save enough after taxes to provide for hard times. Only those who made their stake before the era of high taxes can now feel really secure financially. There are not many consulting firms in the United States today that could weather a protracted period of poor times. While the numbers of firms abound, unfortunately this is largely due to an artificial condition which arises from our overseas technical assistance program. Many of these firms will probably have no permanency. Competition stems from two sources—first on the part of big companies who more and more insist that their geological advice be obtained on a full-time basis from permanent employees. And, finally, there is unrelenting competition on the part of government which provides technical services at cost.

The independent professional is necessary to the health of the mineral industry, and it behooves, then, both the large mining companies and government to recognize this problem and to make whatever contributions they can towards establishing a healthy climate in which the independent professional consultant may prosper. Let us not forget that it was the great consultants of yesterday who made great contributions both to science and to mining geology in general. The wisdom disseminated by these men greatly helped us to meet the demands of the second world war with regard to minerals, and their original ideas are still guiding us in our search for new finds of needed ore deposits.

Further, as to people, we cannot ignore the serious deficiency of scientists and engineers today. Currently, we fall short of engineering and geological requirements by some 60 to 100 thousand men. By 1975 it is presumed that our requirements will be in the neighborhood of 100,000 new technicians a year; yet, we are graduating less than 25,000 annually. Admittedly, the shortage is greatest in the field of aviation and electronics, but a shortage in one field makes for a shortage in all. This matter deserves serious attention—especially in view of the fact that reliable estimates indicate that behind the Iron Curtain more than 100,000 new technicians are turned out annually. Here, again, either in peace or in war the economic welfare of our productive machine centers and depends on technology as the prerequisite for all that follows. An increase in technicians must always precede an increase in plant capacity.

In the years ahead an increasing amount of our mineral requirements must be met from overseas. It is, then, appropriate to study the current picture abroad. Such an appraisal, if made with knowledge and candor, is far from reassuring. In view of the almost worldwide activity of the United States under the Marshall Plan and its successor agencies, my remarks will express largely the United States view, but these thoughts are pertinent here because the several interests of all free nations are involved.

Admittedly, the Marshall Plan was a grand conception, with a high purpose. Albeit, from a mineral procurement standpoint, it was strongly flavored with enlightened self-interest. With the admission of this element in the plan, it followed, as the night the day, that in order for the United States to be successful in obtaining adequate mineral commitments from other nations we were faced with one of the biggest sales jobs this nation has ever known. We had

to sell ourselves in order to establish right human relationships with other nations, for it is these relationships which are the very essence of contractual arrangements in which permanency is vital.

To date the record is unenviable. Where we should have friendliness we have dislike or even hatred. Whereas the contracts we have made should have a basis of faith and mutual trust; instead, far too many are built on the sands of mistrust, and dwell under the shadow of repudiation. In fact, in spite of good intentions and the expenditure of billions of dollars, we can claim few really friendly nations overseas—nations who are convinced that their interests and ours are parallel—who actually believe in us, our ideas and what we stand for. In all too many countries, both we and our motives are mistrusted. The reasons for this are not far to seek: they result from a breakdown in human relationships. Our emissaries went overseas not properly equipped with knowledge of how to be courteous, to promulgate friendliness, trust, and, above all, belief in one another's views and principles. Instead, we went abroad armed with money, superiority feelings, and the big stick of political power. The tactless use of these has damaged our interests gravely.

In this breakdown of relationships, the fault is not entirely ours. We are not the only people in the free world who are immature or arrogant—with the inability to see the other person's point of view. Nevertheless, the proper handling of immaturity demands maturity. Thus, in any attempts to establish right basic relationships with other nations, we must begin with ourselves. We have made too little attempt to put our own house in order before sallying forth on one of the greatest and most complex projects in history. Instead, we largely attempted to force our demands for commitments for steady supplies of mineral material without regard to the importance of first establishing ourselves in the good graces of our neighbors. Commitments with such beginnings will inevitably break down. We assumed we could buy liking, respect, and loyalty, but these are not commodities to be purchased at the marketplace. They are the very essence of lasting covenants between people.

Having ventilated the problem, what is the solution? No quick, easy answer exists. We must achieve the desired ends by means of proper education of all people who have to deal with overseas governments. Time may or may not be on our side, but it appears to me that there is no satisfactory alternative. The situation can only be remedied by commencing with ourselves, and I, therefore, propose that we establish educational programs in government agencies, in our large mining companies, and, above all, in our technical schools and colleges, which will provide our people with the knowledge and understanding that is prerequisite to the establishment of proper human relationships abroad. The instruction should aim to instill in our people the right beliefs, for a man is what he believes. If a man's beliefs are right, it will follow that his conduct will be right. Right beliefs stem from a knowledge of the fundamental values in life. These values are spiritual values, with attendant laws more endlessly true than those of mathematics.

Our people must be taught to believe in humility, compassion, and the ability to see the other fellow's point of view. They must be made to know that all people have the same basic emotions, and are, therefore, basically the same,

regardless of color, creed, or race. They should have engendered in them that feeling of "belonging to the world" which is so fundamental to the establishment of proper relationships between persons. They must believe that the idea of superiority in any material form is an illusion—one of the most damaging illusions, in fact, when it enters into negotiations between persons or governments. They must be taught that to succeed in any enterprise, a man must have integrity, understanding and reverence. It would be well if we could learn with Dr. Alexis Carrell that Prayer is the most powerful form of energy in the universe—the irrefutable proof being that Prayer changes the belief of the person so engaged, and it is beliefs that change the world.

Long ago were laid down the basic tenets for right human relationships; specifically, in the Sermon on the Mount; and, put in simplest terms, the first two Commandments embrace all that it is really necessary to know with regard to human conduct.

And, finally, it is essential to have a central loyalty—a great belief as a focus in life. Emerson gave eloquent voice to this in his essay on worship: "All great ages have been ages of belief . . . when there has been an extraordinary power of performance, when great national movements began, when arts appeared, when heroes existed, when poems were made, the human soul was in earnest and had fixed its thoughts on spiritual verities with as strict a grasp as that of the hands on the sword or the pencil or the trowel," and it is here pertinent to add the geological hammer.

Those who are so hard-bitten, or what is commonly and erroneously called realistic, as to doubt these truths, should be reminded that the great struggle that exists today between the communist countries and the free world is not primarily a battle for either territory or material possessions. The essence of the conflict is a battle for men's beliefs.

In conclusion, and briefly comprehended, the solution of the problem which confronts us will be achieved only through the realization that attitudes are more important than techniques, that people are more important than rocks, and that unless and until we ourselves learn the fine art of human understanding and compassion and the ability to see our neighbor's point of view and to deal with him on a common level, then, regardless of all our knowledge, our money, and our power, we shall not be successful in meeting the mineral needs which are prerequisite not only to our welfare here, but to that of the entire free world.

MINNEAPOLIS, MINNESOTA,
November 23, 1953

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WIDESPREAD OCCURRENCE AND CHARACTER OF URANINITE IN THE TRIASSIC AND JURASSIC SEDIMENTS OF THE COLORADO PLATEAU[1]

A. ROSENZWEIG, J. W. GRUNER, AND LYNN GARDINER

ABSTRACT

Numerous uranium deposits in the sedimentary rocks of the Colorado Plateau contain uraninite. Although this mineral is not restricted to any one formation, the majority of its occurrences are in the Chinle and Shinarump formations of Triassic age. There are two principal modes of occurrence of uraninite, one with sulfides of copper, the other in asphaltic bodies. In both types, the association with fossil plants is the rule. Uraninite generally replaces cell walls of the plants, and the copper sulfides are more apt to fill the cells. Under these conditions the hardness and reflectivity of the uraninite may differ considerably from that of hydrothermal vein uraninite. The paragenesis of the minerals is complex and somewhat obscure, but a formation of the uraninite contemporaneous with, or shortly followed by, copper sulfides is suggested.

INTRODUCTION

URANIUM-BEARING ores from the sediments of the Colorado Plateau have been mined since the early nineteen hundreds. During these early mining operations relatively little attention was paid to the mineralogy of the ores, although several descriptions are available in the literature (1).[2] Throughout nearly fifty years of mining, the mineral uraninite went unnoticed. Early operations did not penetrate into the deeper, unoxidized zones where megascopically visible uraninite occurs. With the advent of the intensive search for uranium during and after World War II, opportunity was presented to make detailed observations of the mineralogy of these deposits. During the past four years many occurrences of this mineral have been brought to light by geologists of the Atomic Energy Commission, its contractors, and the U. S. Geological Survey.

The first discoveries were made almost simultaneously in White Canyon, Utah (2), Placerville, Colorado (3), and Grants, New Mexico (4, 5). Since that time, about 30 occurrences of this mineral have been reported and confirmed from the sediments in the Colorado Plateau.

ACKNOWLEDGMENTS

The writers cannot claim that they discovered all of the occurrences of uraninite mentioned. Some were found and recognized almost simultaneously

[1] Read at the joint meeting of the Geological Society of America and the Society of Economic Geologists, at Boston, Massachusetts, in November 1952.

[2] Numbers in parentheses refer to References at end of paper.

by the staff of the U. S. Geological Survey, the men of the Raw Materials Division of the U. S. Atomic Energy Commission and by us. Others were discovered first by them. References have been given as far as certain regulations permit. We are indebted to the Raw Materials Division of the U. S. Atomic Energy Commission for letting us publish this work which was performed under one of their contracts.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION OF THE URANINITE-BEARING DEPOSITS

The uraninite-bearing deposits of the Colorado Plateau do not differ markedly in distribution or character from the uranium deposits in the sediments in general, and it will therefore suffice to give only a brief, general

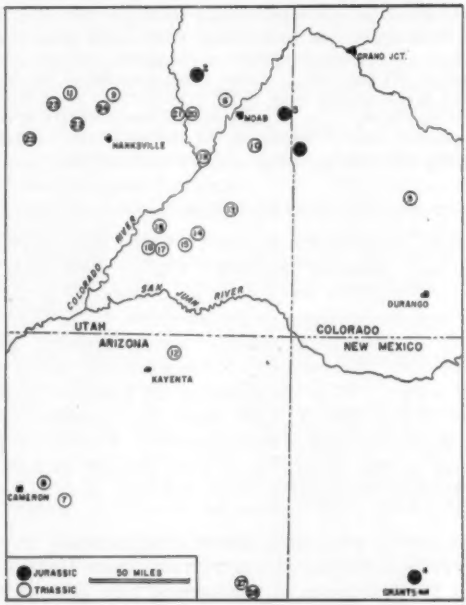

FIG. 1. Occurrences of uraninite.

description of these deposits and their host rocks. Geographically, the uraninite-bearing deposits are to be found in the Plateau as indicated in the index map of the area (Fig. 1). It may be expected that numerous additional occurrences will be found as exploration continues. A list of the actual areas or mines in which uraninite has been found is given in Table I.

Geologically, uranium occurs in sediments of the Colorado Plateau in

many formations from the Pennsylvanian to the Tertiary. To date, uraninite has been observed only in rocks of Triassic and Jurassic age. Uraninite has been found in the Todilto limestone and in the Salt Wash member of the Morrison formation, both of Jurassic age; and in the Chinle formation and the Shinarump conglomerate of Triassic age.

Salt Wash Member of the Morrison (6).—This is a very fine to medium, pink to nearly white sandstone, interbedded with red and green mudstones.

TABLE I

OCCURRENCES OF URANINITE IN THE SEDIMENTS OF THE COLORADO PLATEAU

Location	Formation	Associated Minerals			
		Pyrite	Cu. sulf.	Asphal.	V
1. Grey Dawn, La Sal Creek, Colo.	Morrison	X	X	X	X
2. Yellow Cat District, Utah	Morrison	X		X	X
3. Corvusite mine, Beaver Creek Mesa, Utah	Morrison	X		X	X
4. Grants, N. Mex., Several mines	Todilto	X			X
5. Black King, Placerville, Colo.	Dolores (Chinle)	X	X	X	X
6. Shinarump mines, Seven Mile Canyon, Utah	Chinle	X	X		
7. Hosteen Nez, Tuba City, Ariz.	Chinle	X			X
8. Huskon, Arrow Head mines, Cameron, Ariz.	Chinle	X	X		
9. Temple Mountain, San Rafael Swell, Utah, Several mines	Shinarump	X		X	X
10. Mi Vida, Big Indian Wash, Utah	Chinle	X			X
11. Pay Day, San Rafael Swell, Utah	Shinarump	X		X	X
12. Monument No. 2, Monument Valley, Ariz.	Shinarump	X			X
13. Horseshoe No. 1, North Cottonwood Canyon, Utah	Shinarump	X			
14. Notch, Elk Ridge, Utah	Shinarump	X		X	X
15. Hideout, Deer Flats, Utah	Shinarump	X	X		
16. Happy Jack, White Canyon District, Utah	Shinarump	X	X		
17. Frey No. 4, White Canyon District, Utah	Shinarump	X	X		
17A. White Canyon No. 1, White Canyon District, Utah	Shinarump	X	X		
18. Markie Group, Red Canyon, Utah	Shinarump	X	X		
19. Crab Apple, Inter-River District, Utah	Shinarump	X			
20. A-Group, Inter-River District, Utah	Shinarump	X			?
21. Denise No. 1, Inter-River District, Utah	Shinarump	X			?
22. Delta Group, Muddy River District, Utah	Shinarump	X			
23. Lucky Strike No. 2, San Rafael Swell, Utah	Shinarump	X	X	X	X
24. Wild Horse Nos. 31 & 32, San Rafael Swell, Utah	Shinarump	X			
25. Oyler Tunnel, Capitol Reef, Utah	Shinarump	X			
26. Stinking Spring, Hunt, Ariz.	Chinle	X			
27. Ruth Group, near Petrified Forest, Holbrook, Ariz.	Chinle	X			

Uranium mineralization occurs in the light buff, light brown, and greyish sandstones and is sharply cut off by the mudstone layers. Deposits are commonly concentrated along scours into the mudstone. Many ore bodies are bounded abruptly along curved surfaces within the sandstones forming the so-called "rolls." Carbonized plant fragments and "asphaltic" materials are common in the uranium rich areas.

Todilto Limestone.—This limestone is a fetid, fine to medium-grained, grey limestone up to twenty-five feet thick in the area between Gallup and Laguna, New Mexico. The upper portion of the limestone is generally recrystallized, and has coarse calcite veinlets and pockets within it. Concentrations of uranium may be found in bedding planes, joints, and along small folds and crenulations in the limestone. Locally the hematite content of the limestone is great enough to color the rocks a distinct red. Uranium mineralization does not extend into the Entrada sandstone below, but is found in the Summerville and the Morrison above.

Chinle Formation.—This consists of grey, red, and purple shales and standstone lenses with conglomerates. In southwestern Colorado it is generally referred to as the Dolores formation. Uranium deposits are more common in the lower portions of the Chinle formation. Here the rocks range from shales to coarse sandstones with abundant plant fragments. Silicified logs are very common (Petrified Forest near Holbrook, Arizona, for example). The base of the formation contains limestone pebble conglomerates in a few areas. These form lens-like bodies at the base of the Chinle in contact with the Shinarump or, where the latter is absent, the Moenkopi below.

Shinarump Conglomerate.—The conglomerate is a medium to very coarse sandstone with conglomerates of light buff to grey color. Lenses of grey and green mudstones are very common. Locally the beds are very rich in plant remains and in "asphaltic" materials including liquid or gummy tars and oils. Uranium deposits are commonly concentrated along large elongate scours or "channels" within the formation, and cut into the Moenkopi formation below.

PHYSICAL PROPERTIES OF PLATEAU URANINITES

In megascopic appearance the uraninites of the Plateau vary considerably from one deposit to another as well as within any single deposit. Several of these variations are caused by alteration of the original mineral, but some reflect differences in the mode of deposition or precipitation of the oxide. The massive forms of the uraninite vary from material with a submetallic luster and a hardness of about 5, to a soft (H. ca. 2.5), waxy material. These softer uraninites are generally somewhat oxidized, and also contain less UO_2. They represent alteration either by external chemical processes or by auto-oxidation. A second and distinct form is the black, so-called "sooty" uraninite. This appears as thin layers of a powdery black uranium oxide of indeterminate hardness and dull luster. These two distinct forms of uraninite have been observed side by side within the same deposit, such as at the Happy Jack mine and at Seven Mile Canyon. Megascopically the color of the metallic uraninite is a very dark grey to black; the altered, resinous uraninite may vary from black to brown.

In polished section the unaltered or only slightly oxidized uraninite has a high reflectivity and is grey in color, with a distinct brownish or reddish tint. This color is not readily recognized when uraninite is present alone but will

distinguish it from chalcocite when they are present together. The partially oxidized uraninites have a lesser degree of reflectivity and, in extreme cases, behave as though they were transparent minerals, showing the characteristic dull grey color of such minerals in plane polarized light. In this case the mineral is probably no longer a true uraninite, but almost always encloses minute grains of the brilliant metallic material.

Pieces of pure uraninite, even of very small size, are quite rare, and it was therefore possible to make specific gravity measurements on only a few of the samples. The results of specific gravity measurements, made on a Berman Balance, are given in Table II. The highest specific gravity measured was 9.0. This figure is some 15 percent less than the maximum value for UO_2 quoted by Katz and Rabinowitz (7). The lowest value of 5.4 was obtained on a sample from the Monument No. 2 mine; this sample consists of oxidized material containing small grains of metallic uraninite (Fig. 9).

TABLE II

UNIT CELL EDGE AND SPECIFIC GRAVITY OF COLORADO PLATEAU URANINITES

Occurrence	Cell edge		Sp. g.
*Yellow Cat District, Utah	5.40±.02 Å		—
*Grants, New Mex.	5.38		—
Huskon, Arrow Head mines, Cameron, Ariz.	5.39		—
Copper No. 1, Seven Mile Canyon, Utah	5.39		—
*Shinarump No. 1, Seven Mile Canyon, Utah	5.39	(2)	8.4
Temple Mountain, San Rafael Swell, Utah	5.41		—
Pay Day, San Rafael Swell, Utah	5.38		—
*Monument No. 2, Monument Valley, Ariz.	5.40	(4)	5.4
Happy Jack, White Canyon, Utah	5.40	(3)	9.0
Black King, Placerville, Colo.	5.44	(2)	—

* Unit cell dimensions for uraninites from these localities were supplied by Trace Elements Laboratory, U. S. Geol. Survey. Where duplication occurred the values were found to agree within the above limits.

Unit cell measurements were made on powder photographs. No great degree of precision was obtained in these measurements, but it will be noted that the cell edge dimension is small, the average being about 5.40 as compared with 5.47 of pegmatitic material. Samples showing considerable alteration, e.g. Grey Dawn mine, gave such diffuse patterns that it was not possible to make a measurement of any significance. Cell edge measurements to an estimated accuracy of ± 0.02 Å are given in Table II.

MODE OF OCCURRENCE

Uranium deposits of the Colorado Plateau have been classified by field workers in the area into three types on the basis of their mineral associations. These types are as follows: copper-uranium deposits; vanadium-uranium deposits; and asphaltite deposits. These types are not distinct. They grade

into one another but they do constitute a useful field classification. Uraninite has been found in all of these three ore types. Typical minerals are:

uranium-copper	*uranium-vanadium*	*asphaltite*
uraninite	uraninite	uraninite
copper sulfides	carnotite-tyuyamunite	"asphaltite"
pyrite	"coffinite" [3]	pyrite
	pyrite	

In addition to these, secondary oxidation products are common. The diagnostic mineral associations of the uraninites described in this paper are given in Table I.

Other minerals have been observed in common association with the uraninite-bearing deposits as well as the uranium deposits in general, as mentioned, for example, by Gruner and Gardiner (8). Cobalt, when present, generally forms the carbonate sphaerocobaltite, the sulfate bieberite or is a substituent in other sulfates. The cobalt may be derived from pyrite, although cobalt sulfides have been noted in a few rare cases. Selenium has been found in some of the uranium deposits of the Plateau, although it is only rarely that distinct minerals have been observed. One or two occurrences of copper and silver selenides have been reported. The only association with uraninite observed is at the Corvusite mine, Beaver Mesa, Utah, where the lead selenide clausthalite occurs with uraninite and probably some copper selenides.

Most, if not all, of the deposits in the Colorado Plateau contain large amounts of fossil plants. They are in the form of small flakes of carbonaceous material or of larger wood fragments and logs. Many of the logs are silicified, but within the deposits most of them are carbonized and may contain organic materials. Near Grants, New Mexico, uraninite occurs in a fetid limestone. It is common for the uraninite to replace the fossil material (Figs. 2, 4).

PARAGENESIS

The question of whether the uraninite in the Plateau deposits represents the first stage of uranium mineralization is still unanswered, and is not within the scope of this paper. Although there may be a previous history of this mineralization, the uraninite (and "coffinite"), in general, represents the oldest uranium mineral in the deposits as they exist today. The paragenetic relationships of the uraninite to other minerals in the unoxidized portions of the deposits are not always clearly discernible. This is especially true in "asphaltite" rich deposits.

The replacement of plant remains by uraninite and sulfides presents one of the difficulties in the interpretation of paragenesis. Wood and plant fragments may be completely replaced by these minerals so that their original

[3] "Coffinite" is being investigated by the Trace Elements Laboratory of the U. S. Geol. Survey. It is a new black U-mineral.

structures can no longer be distinguished. They are recognizable as such only on the basis of external form or gradation into unreplaced or partially replaced organic materials. More often the sulfides and uraninite replace the wood cell by cell, in a selective fashion, so that the cellular structure of the plant material is perfectly preserved. Replacement of wood by pyrite is a common phenomenon in the uranium-bearing sediments. This was de-

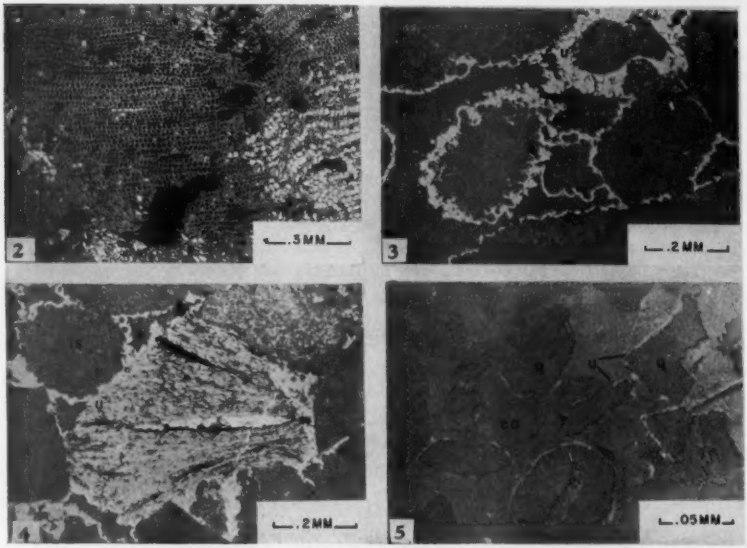

FIG. 2. Uraninite and sulfides replacing wood. Happy Jack mine, White Canyon, Utah. Uraninite (dark grey) replaces cell walls; pyrite (light) and chalcopyrite (medium grey) filling cells. Black areas are unpolished carbonaceous material. (Reflected light.)

FIG. 3. Uraninite (light, u) rimming limestone (ls) grains in the Chinle, Seven Mile Canyon, Utah. Interstitial material is calcite (ca). (Reflected light.)

FIG. 4. Uraninite (u) rimming limestone (ls) and quartz (q); replacing a small plant fragment in the Chinle, Seven Mile Canyon, Utah. Light area at center of replaced plant fragment is chalcocite. (Reflected light.)

FIG. 5. Todilto limestone near Grants, New Mex., showing thin coatings of uraninite (u) on quartz grains in calcite (ca). (Reflected light.)

scribed by B. S. Butler many years ago (9). In almost all cases where cellular structure is preserved, the pyrite fills the cell body, leaving the cell walls unreplaced or free to be replaced by other minerals. Uraninite appears to be later than pyrite and tends to replace the cell walls (Fig. 2). This selectivity of replacement occurs whether either or both minerals are

present. The reverse of this phenomenon has been reported by Finnell,[4] but was not observed by the authors. Copper sulfides replacing wood behave similarly to pyrite in filling the cells, but they appear to be later than the uraninite. This selective replacement makes paragenesis difficult to interpret, and the sequence pyrite-uraninite-chalcopyrite must be inferred from cases in which wood is replaced with a lesser degree of structure preservation. Unreplaced portions of the wood appear as sooty material which may contain some sooty carbonaceous stuff and uraninite (Fig. 2).

Much of the uraninite at the Happy Jack mine occurs intimately intergrown with copper sulfides in the form of irregular tabular masses, in the aggregate a fraction to several inches in thickness. These show some wood structure and may represent seams of plant debris which have been almost completely replaced. There appears to be an overlapping of the uraninite-copper sulfide formation or two stages of copper sulfide deposition. Stringers of uraninite cut an intergrowth of chalcopyrite and bornite and are later cut by chalcopyrite free of bornite. Uraninite has not been observed in contact with bornite; covellite forming a boundary between them. Some chalcocite at the Happy Jack deposit could possibly have been formed by secondary enrichment, seemingly occurring more abundantly in the less deeply buried portions of the deposit.

At Seven Mile Canyon, Utah, uraninite occurs in a calcareous sandstone that locally contains lenses of a limestone pebble conglomerate. Uraninite occurs in some portions of this conglomerate as a thin coating on limestone grains and quartz grains (Figs. 3, 4). Chalcocite, and rarely chalcopyrite, is enclosed in the uraninite rim. The interstitial material is generally calcite but in a few instances bornite fills the spaces; a thin zone of chalcocite and covellite separates it from the uraninite. Small plant fragments, as well as logs, within this conglomerate are also replaced by uraninite (Fig. 4), and the continuity of uraninite rims and plant replacement suggests that both are formed under the same conditions. A similar rimming of quartz grains by uraninite occurs in the Todilto limestone at Grants, New Mexico (Fig. 5).

Two generations of chalcocite are apparent in the Seven Mile Canyon deposit. The first, described above, is generally of distinct blue color in polished section and always contains small "feathers" of covellite. The second is almost white and clearly later. It replaces uraninite in the fossil material and fills interstices in the conglomerate, corroding the uraninite rims (Fig. 6).

The "asphaltite" deposits present a different pattern (1), (10, p. 14). In general, few copper minerals are found, and the only common and abundant sulfide is pyrite. Most of these deposits are much richer in vanadium than those described above, as may be seen in Table I. The "asphaltite" of these deposits is not a true asphalt such as gilsonite, but a hard, brittle, shiny to dull black material, that is not readily attacked by ordinary organic solvents. Many of the uranium rich "asphaltites" show no visible uraninite under the microscope. Where it is observed, however, it is gen-

[4] Finnell, T. L., Symposium of A. E. C. and U. S. Geol. Surv. at Grand Junction, Colorado, 1953.

erally so fine-grained that the existence of submicroscopic uraninite in other samples is probable. No conclusions have been reached as to the origin of the "asphaltite" itself. It has been suggested by Davidson and Bowie (11) that it may form by the polymerization of light hydrocarbons under alpha particle bombardment. These hydrocarbons could be derived from plant material within the sediments or from organic liquids migrating through

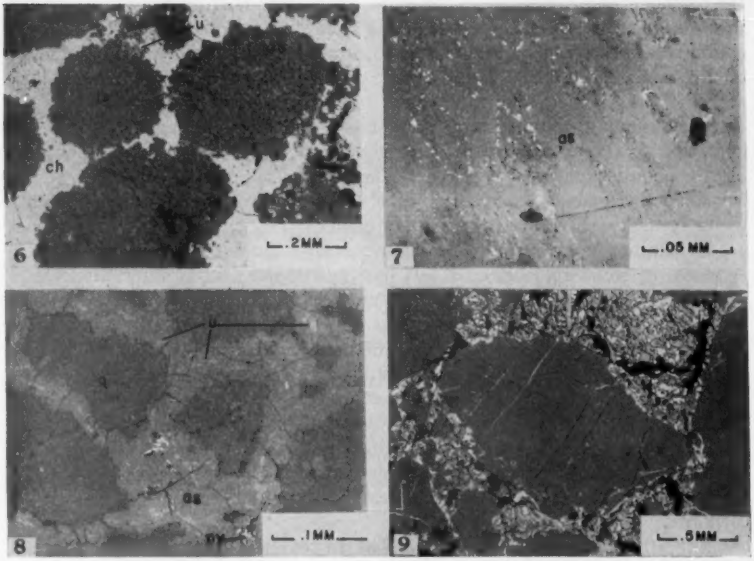

FIG. 6. Remnants of uraninite rims (u) corroded by white chalcocite (ch) in limestone conglomerate in the Chinle, Seven Mile Canyon, Utah. (Reflected light.)

FIG. 7. Uraninite and pyrite grains in ellipsoidal pattern in "asphaltite." Note the approximate parallelism of the ellipsoidal groups. (Reflected light.)

FIG. 8. Interrupted stringers of uraninite (u) paralleling corroded quartz grains in "asphaltite." Pyrite (py) is scattered through the "asphaltite." Notch claims, Elk Ridge, Utah. (Reflected light.)

FIG. 9. Uraninite (white) in a matrix of altered uraninite (light grey) and in fractures in quartz grains. Black areas are unpolished. Monument No. 2 mine, Monument Valley, Ariz. (Reflected light.)

the uranium-bearing beds. If this concept were correct, the uranium deposits would be older than the "asphalt."

At Temple Mountain, Utah, uraninite was found, together with pyrite, forming small ellipsoidal rings of similar orientation within a uniform mass of "asphaltite" (Fig. 7). These structures are too small for detailed study, but the elongate cellular pattern suggests an original wood structure, partially

replaced by uraninite and pyrite, and then completely replaced by "asphaltite," leaving the metallic minerals as the only trace of the original structure. Most of the uraninite in the Temple Mountain area occurs as these very small grains arranged in such patterns, or scattered at random through the "asphaltite."

At the Notch No. 1 claim, Elk Ridge, Utah, an extremely interesting occurrence of uraninite in "asphaltite" is to be found. Quartz grains in the asphalt rich sandstones at this mine show deep corrosion with interstitial uranium-bearing "asphaltite." In the richest specimens the "asphaltite" contains broken stringers and ribbons of uraninite that parallel the boundaries of the corroded quartz grains (Fig. 8). The analogy to the uraninite coated quartz of the Seven Mile Canyon area is strongly suggested. Samples were examined to determine whether any intermediate agent caused the corrosion of the quartz but no evidence of other minerals than "asphaltite" at the boundary could be found. The possibility of the organic material attacking the quartz seems very unlikely, but in view of the lack of evidence to the contrary, should be investigated further.

Uraninite [5] occurs at the Monument No. 2 mine, Monument Valley, Arizona, as wood replacements. It has been found also as interstitial material between quartz grains and along fractures in broken quartz grains (Fig. 9). The uraninite in this mine is rarely unaltered. Most commonly it appears in the form of small grains of high reflectivity in a matrix of greenish or brownish black resinous material similar to the darker forms of gummite, but very rich in vanadium. This material is generally surrounded by a thick zone of the secondary uranyl vanadates, tyuyamunite and metatyuyamunite. A similar sequence of alteration has been found by Rasor (12) near Grants, New Mexico, and the Grey Dawn mine, La Sal Creek, Colorado. At the latter locality, however, the final product contains considerable carnotite.

Alteration of the uraninite in the Plateau sediments as mentioned above is almost the rule. In general, where the ores are rich in vanadium the secondary minerals formed are the uranyl vanadates carnotite, tyuyamunite, and metatyuyamunite. In the copper sulfide-rich deposits, uranyl sulfates are the common secondary minerals.

CONCLUSIONS

Uraninite is not an uncommon mineral in the uranium deposits of the Colorado Plateau. In some mines such as the Happy Jack, White Canyon, Utah, and Seven Mile Canyon, Utah, it forms the major ore mineral of uranium. It may be expected that uraninite will be found in greater abundance in other areas of the Plateau as mining operations penetrate deeper into less oxidized ore bodies.

The uraninite occurrences are widely distributed geographically and lithologically and are commonly associated with vanadium, copper and manganese, though these elements are not necessarily all present. Pyrite

[5] The mineral was first reported by the staff of the U. S. Geol. Survey.

has been found in all of the uraninite-bearing deposits regardless of the nature of the host rock and associated minerals. Organic material in the form of wood, plant fragments, or "asphaltite" is another universal constituent of these deposits. These facts strongly suggest that the controlling factor in the formation of uraninite in the sedimentary rocks of the Colorado Plateau is the existence of a strongly reducing environment rather than any lithologic setting. Unsilicified fossil wood and plant fragments, in addition to other contributing reducing agents, form an ideal medium for the precipitation of uraninite as evidenced by the numerous examples of wood replacement.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
Oct. 23, 1953

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COPPER CITIES COPPER DEPOSIT, GLOBE–MIAMI DISTRICT, ARIZONA [1]

N. P. PETERSON

ABSTRACT

The Copper Cities copper deposit in the Globe-Miami district, Arizona, is now in process of development. It is of the "porphyry" type and occurs in a body of quartz monzonite that has been intruded by smaller masses of granite porphyry. The hypogene sulfides are pyrite, chalcopyrite, and a very little molybdenite. Pyritic mineralization extends over a large area of which only a small portion contains an appreciable amount of chalcopyrite. The outcrop of the copper-bearing rock, roughly 1,800 feet square, is bounded on the west, north, and east sides by fault zones. The south boundary is gradational. The pyrite to chalcopyrite ratio of the protore increases rapidly with depth, whereas the copper content decreases but slightly. The ore body is a shallow chalcocite zone formed by supergene enrichment. Bodies of granite porphyry within the copper-bearing area were not as strongly mineralized by hypogene solutions as the quartz monzonite, and in them the chalcocite zone is thin, undoubtedly because the granite porphyry is less pervious to ground water than the quartz monzonite.

INTRODUCTION

THE Copper Cities disseminated copper deposit in the Globe-Miami district, Gila County, Ariz. is on the south flank of Sleeping Beauty Mountain, 3½ miles due north of Miami. The ore body straddles the middle part of the common boundary between the Globe and Inspiration 7½-minute quadrangles as mapped by the U. S. Geological Survey in 1945. The Globe-Miami district was studied by F. L. Ransome (2, 3, 4) [2] of the Geological Survey in 1901 and 1902. The Geological Survey has recently completed remapping the geology of the district in much greater detail.

The weathered quartz monzonite outcrop of the Copper Cities area, which has the characteristics of leached capping, attracted some attention as a possible indication of a disseminated copper deposit about the time the Miami-Inspiration ore body was being explored. The first serious attempt to explore the Copper Cities property was begun in 1917 by the Louis d'Or Mining and Milling Co. By the end of 1922, a shaft 360 feet deep and 12 drill holes totaling nearly 9,000 feet had been sunk. The results showed the presence of disseminated copper minerals, but the deposit was too low in grade to be considered ore at that time. Further exploration by drilling was done in 1929 and 1930.

Miami Copper Co. purchased the property in 1940. Copper Cities Mining Co., a subsidiary of Miami Copper Co., was organized to operate the property.

[1] Publication authorized by the Director, U. S. Geological Survey.
[2] Numbers in parentheses refer to References at end of paper.

Systematic exploration by churn drilling was started in 1943 and completed in 1948. A low-grade ore body reported by the company to contain 33,000,000 tons amenable to open-pit mining methods had been blocked out.

Development work preparatory to exploitation of the ore body was begun in the latter part of 1950. The development program has been geared with the depletion of the Castle Dome deposit so that production can begin as soon as the concentrator and other facilities at Castle Dome have been moved to prepared sites at Copper Cities. It is expected that production of copper concentrates at Copper Cities will begin during the latter part of 1954. In 1953, stripping operations were in progress on the 4,005-foot level of the open-pit mine.

ACKNOWLEDGMENTS

The writer is indebted to R. W. Hughes, General Manager, B. R. Coil, Assistant General Manager, and members of the engineering staff of Copper Cities Mining Co. for their cooperation. C. M. Gilbert and G. L. Quick assisted in the mapping and study of the Copper Cities area.

GENERAL GEOLOGY

A somewhat generalized geologic map of the Copper Cities area is shown in Figure 1. The basement formation of the district is the Pinal schist of lower Precambrian age. In the vicinity of Copper Cities, the schist was intruded by large masses of Ruin granite and many small bodies of dioritic rocks. A profound unconformity separates these lower Precambrian rocks from the overlying sequence of sedimentary formations that includes the upper Precambrian Apache group, the Cambrian Troy quartzite, Devonian Martin limestone, Mississippian Escabrosa limestone, and Pennsylvanian Naco limestone.

Probably in late Cretaceous or early Tertiary time, the Lost Gulch quartz monzonite, the diabase, and granite porphyry were intruded, and they were followed by a period of copper mineralization.

The upper Precambrian Apache group and the sedimentary formations of Paleozoic age and included bodies of intrusive rock are separated from the younger formations by another great unconformity so that the Whitetail conglomerate and dacite lava flows of early Tertiary(?) age may rest on any one of them. Similarly, the Gila conglomerate of late Tertiary and Quaternary age may rest on the dacite or any of the older formations. Recent erosion has removed the Gila conglomerate from large areas, and alluvium has accumulated along the channels of intermittent streams.

The rocks that are most important in their relationship to the copper deposit are Lost Gulch quartz monzonite and the granite porphyry. These rocks are respectively identical petrographically with the quartz monzonite and granite porphyry of the Castle Dome area and undoubtedly should be correlated with them.

The quartz monzonite consists essentially of quartz, orthoclase, oligoclase, and biotite. Like that at Castle Dome (1, p. 24–26), it comprises two

textural varieties. One variety is porphyritic quartz monzonite containing large phenocrysts of pale-red orthoclase in a coarse-grained groundmass, the other is quartz monzonite porphyry containing large orthoclase phenocrysts and smaller ones of quartz, oligoclase, and biotite in a fine-grained groundmass. Most of the ore at Copper Cities occurs in the coarse-grained variety, but this is not because it is a more favorable host rock, for at Castle Dome there is no appreciable difference in the metallization in adjacent bodies of the two facies of quartz monzonite.

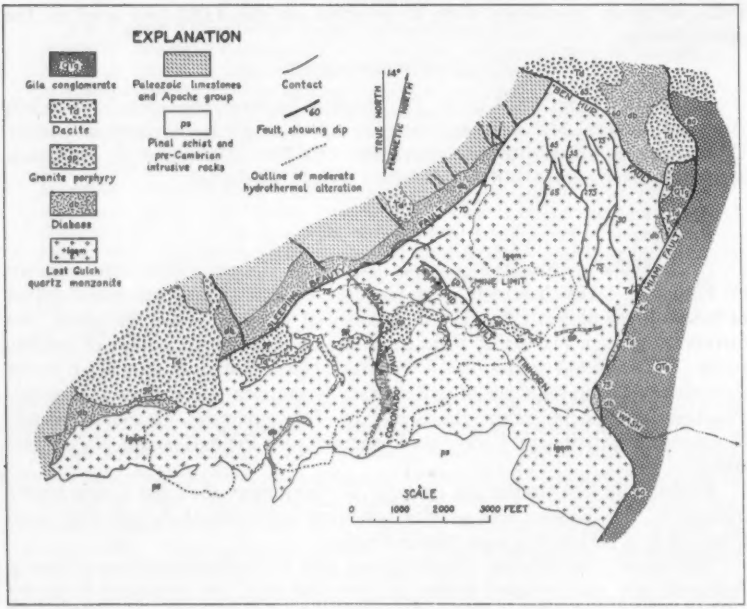

FIG. 1. Geologic map of the Copper Cities area.

The granite porphyry contains phenocrysts of euhedral quartz, pale-red orthoclase, oligoclase, and biotite in a microcrystalline groundmass of quartz, orthoclase, and a little plagioclase. It is so similar to the granite porphyry at Castle Dome and to the granite porphyry facies of the Schultze granite stock in the southern part of the Inspiration quadrangle that all are believed to be related intrusions.

STRUCTURE

The outcrop of Lost Gulch quartz monzonite is a relatively elevated, northeast-trending block that is bounded on three sides by faults (Fig. 1).

Along the east side, the boundary is made by the east-dipping Miami fault,

which drops Gila conglomerate into contact with quartz monzonite. The Miami fault is one of the most prominent structural features of the Globe-Miami district. It forms the contact between Gila conglomerate and the older formations for a distance of about 8 miles along the west side of a depressed block that underlies a broad alluviated valley between the towns of Globe and Miami. The throw on the fault along the quartz monzonite outcrop is not known, but it may well exceed 1,000 feet. Farther south in the vicinity of the Miami-Inspiration ore body, the throw is about 1,500 feet. Near the northeast corner of the quartz monzonite outcrop, the fault swings west; and a little farther north, its identity is lost in a complex network of normal faults some of which depress the blocks to the west and probably are related to the Pinal Creek fault system, which forms the east boundary of the depressed Globe Valley block.

The Gila conglomerate east of the quartz monzonite outcrop probably is underlain by dacite. Narrow blocks of dacite crop out along the fault zone; and to the east along the west side of Pinal Creek, the conglomerate overlaps dacite that is lying on an irregular erosion surface of diabase. The Miami fault undoubtedly displaces quartz monzonite, but it is very near the east side of the mass.

The Ben Hur fault, which forms the northeast boundary of the quartz monzonite, strikes N 45° W and dips 60° to 65° NE. The block to the northeast has been dropped so as to bring diabase, in part overlain by dacite, into contact with the quartz monzonite. This diabase probably is a sill-like body intruded between quartz monzonite and the sedimentary formations of the Apache group. It includes many blocks of Pioneer formation some of which have smaller blocks of quartz monzonite faulted into them.

On the northwest side, the quartz monzonite outcrop is bounded by the Sleeping Beauty fault along which the adjacent block has been relatively depressed. The Sleeping Beauty fault strikes northeast; the dip is uncertain, but probably is about vertical or steeply southeast. Probably a major part of the displacement along the fault occurred before the diabase intrusion. A thick diabase dike has been intruded along it. Later displacement occurred along the diabase-quartz monzonite contact.

The sedimentary formations northwest of the fault have been intricately faulted and form a mosaic of limestones of Paleozoic age and rocks of the Apache group. Most of the faults strike northwest approximately at right angles to the strike of the Sleeping Beauty fault. Some of these faults are overlapped by dacite, and some displace the dacite. The general dip of the strata in the faulted blocks is from 20° to 50° SW, but there are many local exceptions. At the north end of the quartz monzonite outcrop, the beds form a minor anticline whose axis trends northwest roughly parallel to the Ben Hur fault. To the southwest where the diabase dike is thickest, the adjacent beds dip very steeply or are slightly overturned.

Along the south side, the quartz monzonite is in normal intrusive contact with Pinal schist and the various dioritic intrusive rocks of the Precambrian igneous complex. The contact is very irregular and appears to be generally steep. It is not displaced by any major faults.

The structures most important in their relationship to the ore body are the Coronado and Drummond fault zones, which limit the copper metallization on the west and east sides respectively. The outcrop of the Coronado fault for 2,000 feet along the west side of the ore body is a sheared and brecciated zone from 100 to 300 feet wide. It strikes north and dips steeply west. At the north and south ends of this broad zone, the fault swings westward and in a distance of a few hundred feet appears to contract to such a minor fissure that its outcrop is scarcely recognizable. However, recent stripping operations at the north end of the fault have exposed a strong gouge

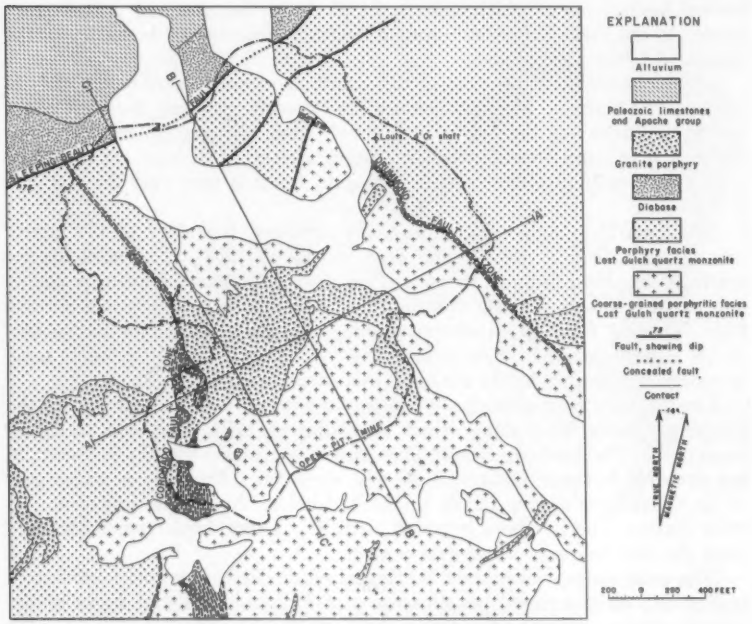

FIG. 2. Geologic map of the copper-bearing area.

zone that extends to the Sleeping Beauty fault. Where the outcrop is widest and most prominent, it is the boundary between the two facies of the Lost Gulch quartz monzonite, porphyritic quartz monzonite on the east or footwall side and quartz monzonite porphyry on the west side (Fig. 2). Whether this relationship continues in depth in uncertain. Small lenticular bodies of diabase have been intruded along the fault. Outcrops of granite porphyry within the fault zone do not appear to be appreciably sheared or displaced, but recent excavations along the fault reveal strong evidence of displacement later than the mineralization.

The Drummond fault is much less prominent than the Coronado, but in other respects, the two faults are similar. The outcrop is a narrow zone of silicified breccia generally less than 25 feet wide. It strikes N 45° W and dips 60° NE. Like the Coronado fault, it forms the boundary between the two facies of the quartz monzonite along most of its recognizable extent. On the 4,005-foot level of the mine, the northwestern part of the fault is a zone of black gouge about 6 feet wide that continues to the Sleeping Beauty fault. To the southeast beyond the mine limits, the outcrop of the fault becomes too indistinct to identify.

Northeast of the Drummond fault, the quartz monzonite is traversed by many faults that strike north to northwest and dip 50° E to vertical. These faults appear in outcrops as narrow zones of silicified breccia, but the displacement along them must have been relatively slight. Most of these faults are older than the diabase, and many of them have small, irregular masses of diabase intruded along them particularly at points of intersection.

The mineralized quartz monzonite is intricately dissected by joints, fractures, and minor faults, some older and some younger than the mineralization. The premineral fractures are now occupied by quartz-pyrite and chalcopyrite veinlets. Within the mine area east of the Coronado fault, no dominant pattern of veinlets or joints has yet been recognized. In many places, it is difficult to find a hand-sized fragment of rock that is not bounded on one or more sides by walls of veinlets. Postmineral fractures and minor faults are abundant. Some of the minor faults are so recent that they displace the boundary between leached capping and the top of the ore body.

The mine benches that have been excavated into the rock west of the Coronado fault show a prominent system of closely spaced fractures and veinlets that strike N 30° to 70° E and dip steeply SE. There also are many minor faults of similar strike and dip. Wherever the direction of movement can be determined, the blocks to the southeast are depressed generally less than 20 feet.

MINERALOGY OF THE DEPOSIT

The mineralogy of the Copper Cities deposit is fairly simple and in most respects is like that of the other disseminated deposits of the district. The principal hypogene minerals are quartz, pyrite, chalcopyrite, and molybdenite. Pyrite is by far the most abundant hypogene sulfide. The relative proportion of pyrite to other sulfides is probably higher than in the copper-bearing zones of the other disseminated deposits of the district. Pyrite occurs in veinlets with quartz and a little chalcopyrite and is associated with strong sericitic alteration.

Chalcopyrite is next in abundance but is not as widely distributed as pyrite. It is confined mainly to the block between the Coronado and Drummond fault zones. In addition to that in the quartz-pyrite veinlets, chalcopyrite occurs also in quartz veinlets containing little or no pyrite, and as discrete grains disseminated in the host rock between the veinlets. The relative importance of the three modes of occurrence is as yet unknown, but it appears likely that

more than half of the chalcopyrite is in the form of disseminated grains. The chalcopyrite in the quartz-pyrite veinlets is intergrown with pyrite, but no clear-cut evidence of replacement of either mineral by the other has been found.

Neither molybdenite nor its oxidation products were recognized in the leached capping over the ore body, but occasional flakes were seen in the concentrates panned from drill sludges. The molybdenum content of the rock within the limits of the ore body has been estimated at about 0.004 percent, which is much less than that of the other disseminated deposits of the district.

Rock fragments cut by quartz veinlets containing molybdenite are common in the dump of the Louis d'Or shaft, which was sunk at the eastern edge of the copper-bearing area, near the outcrop of the Drummond fault (Fig. 2). In the place from which the dump rock was mined, probably within the Drummond fault zone, quartz-molybdenite veinlets must have been abnormally abundant and apparently traversed rocks affected by strong pyritic metallization and strong silicic and sericitic alteration.

Sphalerite and galena have not been recognized in the drill sludges, but a few specimens have been found in the broken rock from stripping operations along the Coronado fault zone. No veins showing evidence of having contained sphalerite or galena were recognized in the outcrops in the mine area. A small shoot of sphalerite and argentiferous galena has been mined from a short vein in the schist a few feet from its contact with the quartz monzonite on the Cedar Tree claim, 3,000 feet southwest of the Copper Cities mine. Other small sphalerite and galena veins occur in the schist farther southwest.

Chalcocite and covellite are the only supergene sulfide minerals in the deposit. Chalcocite formed by replacement of chalcopyrite in the enriched zone and to a very minor extent as a replacement of pyrite. Its occurrence, therefore, is the same as that of the replaced minerals. A little covellite may have formed by direct replacement of chalcopyrite, but most of it is an alteration product of chalcocite. It is largely confined to the upper part of the chalcocite zone.

Malachite, azurite, and turquoise account for most of the acid-soluble copper in the ore body and for the small amount of copper that remains in the leached capping. Turquoise was commonly seen in drill sludges, and it is abundant in and around small prongs of the ore body that have been encountered during the current stripping operations. Most of it is the soft chalky variety, but some of it is hard enough to be of gem quality. Much of the hard turquoise is the greenish ferrian variety.

A few flakes of metatorbernite have been seen in the drill sludges, and a little has already been uncovered in the mine. It occurs as the usual tiny rosettes on the walls of minute fractures in the granite porphyry along the Coronado fault zone.

The expectancy that most of the mineralogic details of the Castle Dome deposit will be found to characterize the Copper Cities deposit seems well assured by the great similarity of the broader geologic features of the two deposits.

HYPOGENE MINERALIZATION

The hypogene metallization and accompanying hydrothermal alteration is confined to the quartz monzonite and the bodies of granite porphyry and diabase that have been intruded into the quartz monzonite except in a few places along the south side of the deposit where the effects of weak hydrothermal alteration can be detected in the adjacent schist and dioritic rocks. The outcrop of mineralized rock measures about 10,000 feet from southwest to northeast and about 3,000 feet wide. Its long axis trends N 60° E, approximately parallel to the Sleeping Beauty fault. Its general shape is represented by the limit of moderate hydrothermal alteration as shown in Figure 1. This outline was plotted using arbitrary standards and therefore is subject to considerable variation owing to personal factors.

Along the northwest side, mineralization is generally strong up to the Sleeping Beauty fault, but the diabase north of the fault shows no evidence of hypogene mineralization. In other directions, the effects of mineralization gradually fade out. Throughout this area, the rocks contain many steeply dipping quartz-pyrite veinlets. In outcrops, the pyrite is completely oxidized and mostly leached. The resulting voids are partly filled by powdery or granular limonite or sintery crusts of dark-brown transported limonite.

The pyritic metallization is strongest along the Sleeping Beauty fault and along the Coronado and Drummond fault zones as evidenced by the bright red and yellow coloration of the outcrops compared with the light-brown coloration that pervades the rest of the mineralized area.

The copper metallization is confined largely to the block lying between the Coronado and Drummond fault zones, which is in the northeastern part of the mineralized area. It appears to be strongest in the quartz monzonite bordering the granite porphyry intrusive bodies and locally in the granite porphyry itself. The estimated copper content of the unenriched protore within the limits of the ore body as determined by detailed studies of several exploratory drill holes, ranged from about 0.25 to 0.6 percent. The average was about 0.4 percent. In general, the protore in the granite porphyry appears to be somewhat lower grade and probably contained from 0.15 to 0.35 percent copper. Near the southern edge of the ore body, the tenor of the protore is 0.15 to 0.25 percent copper, and farther south the copper content gradually decrease to the outer limit of mineralization.

Although the mineralized rock was raised to ore grade as a result of supergene enrichment, the copper content of the protore within the vertical limits of the ore body appears to have been higher than in the unenriched or slightly enriched protore below the ore body. There appears to be a progressive decrease in the copper content of the protore with increasing depth.

Much more pronounced is the increase in the pyrite to chalcopyrite ratio with depth. Within the limits of the ore body, the pyrite to chalcopyrite ratio ranged from 1.2 to 9, the average was about 3.6; whereas below the ore body, the ratio ranges from 4 to 16, the average being about 10. Since the low ratios occur in rock that has undergone considerable supergene enrichment and the high ratios in rock showing but slight or no enrichment, it might

be inferred that the difference is the result of supergene processes. However, study of the sulfide concentrates from exploratory drill holes shows clearly that replacement of pyrite by chalcocite or covellite is practically negligible.

The lower pyrite to chalcopyrite ratios within the limits of the ore body may be partly the result of replacement of pyrite by chalcopyrite during hypogene metallization of the deposit, but this process could only be a minor cause. Examination of sulfide concentrates shows few grains in which pyrite and chalcopyrite are in contact. The boundaries between the two minerals are smooth and regular and give no conclusive evidence of replacement or difference in age. The hypogene metallization clearly shows a substantial increase in the proportion of pyrite with depth.

The thickest and richest ore is in the quartz monzonite along the south side of the granite porphyry mass that crops out across the central part of the block between the Coronado and Drummond fault zones (Fig. 3). In places, rock averaging 0.5 percent copper continues to depths of 600 feet or more below the leached capping. The ore is thick, mainly because the hypogene copper metallization is stronger here than elsewhere in the deposit. In the upper part of this thick ore, the copper content has been approximately doubled by supergene enrichment. In the lower part, very slight enrichment was sufficient to raise the copper content above the cut-off grade. There has been very slight or no enrichment below a depth of about 300 feet.

Hydrothermal Alteration.—A complete and detailed study of the hydrothermal alteration that accompanied the metallization at Copper Cities has not been undertaken. However, the general characteristics of the alteration appear to be similar in most respects to those observed in the Castle Dome area (1, p. 71–88). The host rocks of the two deposits are petrographically identical, and the metallization is of the same general character. In both deposits the same three alteration phases are represented, a quartz-sericite phase, an argillic or clay phase, and a very feeble border phase in which minerals of the propylitic type are present. The most apparent difference is in the areal distribution of the alteration products in relation to the copper ore body.

After reviewing most of the southwestern "porphyry copper" deposits, Schwartz (5, p. 351) concluded that chalcopyrite was introduced largely with the sericitic mineralization. At Copper Cities as well as at Castle Dome, some sericitic alteration undoubtedly accompanied deposition of chalcopyrite, but the major part of the quartz-sericite alteration is clearly related to the pyritic metallization. Each quartz-pyrite veinlet is bordered by a narrow zone in which the original texture of the rock has been completely destroyed, and the rock minerals except the quartz grains have been replaced by sericite or hydrous mica and quartz. The widths of the alteration borders are roughly proportional to the amount of pyrite contained in the veinlets. Where the pyritic metallization is most intense and the veinlets most numerous, most of the plagioclase of the intervening rock has been replaced by sericite. In some places the alteration borders coalesce, and the wall rock is completely replaced by sericite and quartz.

Complete silicification, which is the ultimate effect of quartz-sericite

alteration, is far more common than in the Castle Dome area. Silicic replacement is strong along some faults and breccia zones, and in a few places the quartz monzonite and granite porphyry have been completely replaced by quartz and disseminated pyrite.

Argillic alteration, in which the plagioclase of the rocks is replaced by a colorless or slightly yellowish clay mineral of the montmorillonite type, pervades the rock between the veinlets throughout the area that has been appreciably mineralized. The affected rocks look almost fresh, but the alteration can be detected by chalky appearance of the plagioclase and in some places by bleaching and replacement of biotite. The relative intensity of the clay alteration can be gauged roughly by the hardness of the plagioclase and by the ease with which the grains disintegrate in water. More or less fine-grained sericite or hydrous mica is present in all the argillized grains.

A very feeble but entirely different type of alteration in the outer fringes of the mineralized area extends beyond the limits to which appreciable evidence of the other types of alteration can be recognized in the field. The minerals developed are those characteristic of propylitization, namely chlorite, epidote, pyrite, a little sericite, and probably also calcite and clinozoisite as at Castle Dome (1, p. 72–73). This alteration is so feeble that it is difficult to detect except by microscopic examination. The only megascopic evidence of its effects on the quartz monzonite are slight chloritic alteration of biotite and occasional grains of pyrite near biotite books.

The quartz-sericite is superimposed on the clay alteration in the sense that the clay alteration front reached a given horizon somewhat in advance of the quartz-sericite front. Except in the areas of strongest alteration in which much of the clay is assumed to have been replaced by sericite, the intensity of one phase appears to differ proportionally with that of the other. Thus, both phases are regarded as the result of a single process related mainly to the quartz-pyrite mineralization.

ZONING

In the Copper Cities deposit, there is no clear evidence of lateral zoning in the distribution of metals comparable with that displayed in the Castle Dome deposit. The copper-bearing area occupies a more central position with respect to the pyritic metallization than is commonly true of disseminated copper deposits. There is, however, strong evidence of vertical zoning as shown by the increase in the pyrite-chalcopyrite ratio with depth.

Practically all the exploratory drill holes show a definite decrease in the copper content of the rock with increasing depth below the bottom of the leached capping. In many of the shallower holes, this decrease is largely the result of a decrease in the amount of secondary chalcocite with depth. However, there are many holes that extend well below the limits of supergene enrichment, and most of these are bottomed in rock that carries from 0.2 to 0.35 percent copper. Computations of the original grade of the protore before enrichment in a few selected holes, which are based on the amount of

chalcopyrite replaced by chalcocite, show a small but definite decrease in the copper content of the protore with increasing depth. A deep hole drilled in the southwestern part of the ore body near the granite porphyry contact where mineralization is relatively strong, showed intersections ranging from 0.3 to 0.6 percent copper to a depth of 1,225 feet. From 1,225 feet to the bottom at 1,500 feet, the copper content averaged 0.23 percent.

The outcrop of copper-bearing rock that includes the ore body is roughly 1,800 feet square. Its rectangular outline was controlled by the Coronado, Sleeping Beauty, and Drummond faults, which clearly limit the copper metallization on the west, north, and east sides. The large body of granite porphyry that crops out just east of the Coronado fault forms an irregular core near the middle of the western side of the copper-bearing rock. From the east side of granite porphyry body, a dikelike apophysis extends northeastward to the Drummond fault and another southeastward a little beyond the mine limits (Fig. 2). The richest hypogene copper metallization appears to have been localized around these granite porphyry bodies.

The granite porphyry bodies within the mine area are a segment of a chain of similar intrusive bodies that have such a definite easterly alinement as to suggest that they were controlled by a deeply rooted structure. Furthermore, the spatial relationship of the general pyritic mineralization to this chain of intrusions and that of the copper metallization to the intrusive bodies within the mine area suggest that the mineralizing solutions also came up along this structure.

The vertical zoning of the metallization may possibly be the controlling factor in the localization of copper in the Copper Cities deposit. The copper-bearing area may well be the outcrop of a block that has been relatively depressed by postmineral displacement along the Coronado and Drummond fault zones, so that it represents a shallower horizon than the pyritic rock that crops out in the blocks to the west and east. If this is true, at least the postmineral displacement along these faults is reverse as the copper-bearing block forms the footwall of both faults.

AGE OF THE HYPOGENE MINERALIZATION

The hypogene mineralization at Copper Cities shows exactly the same age relationships as those of all the copper deposits of the district (1, p. 107–108). It is younger than the diabase, quartz monzonite, and granite porphyry intrusions but is older than the Whitetail conglomerate, which was deposited during the period of erosion that preceded the dacite eruption.

The close association of most of the copper deposits of the district with bodies of granite porphyry suggests that the mineralizing solutions ascended along the same channels as the granite porphyry and probably had their source in the same magma chamber. The granite porphyry is believed to be a late facies of the Schultze granite which probably was intruded in late Mesozoic or early Tertiary time and was followed by a period of mineralization that produced the large copper ore bodies of the Globe-Miami district.

GROUND WATER LEVEL

The mine area straddles the upper reaches of Tinhorn Wash, a tributary of Pinal Creek 2 miles to the east. The topography and drainage pattern is governed to a large extent by the relatively resistant outcrops of granite porphyry. The surface has a general southeasterly slope in the direction of the gradient of the main wash. The maximum relief is about 450 feet. Altitudes range from 4,250 feet on the top of the highest hill in the northwestern part of the mine area to 3,800 feet in the bed of Tinhorn Wash where it crosses the southeastern limits of the mine.

The ground water level, as determined during the exploratory drilling of the copper deposit, also has a general southeasterly slope (Fig. 3) approxi-

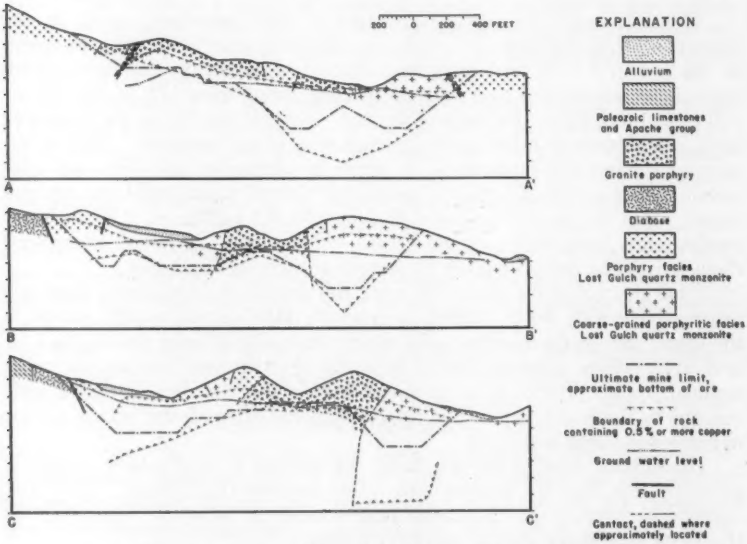

FIG. 3. Cross sections of the Copper Cities ore body.

mately the same as the bed of Tinhorn Wash. It ranges in elevation from 4,000 feet in the northwestern part of the mine area to 3,700 feet in the southeastern part. In detail, it reflects most of the major topographic features and also is influenced by geologic structure and rock formations. It is higher in granite porphyry bodies than in the surrounding quartz monzonite. Contours on the water table clearly reflect the position of the large granite porphyry body that lies within the mine area.

The main circulation of ground water appears to follow the course of Tinhorn Wash and undoubtedly is controlled by the same gap in the east-trending barrier formed by the granite porphyry bodies that controlled the

course of the wash. There is a secondary channel of underground flow along the Coronado fault shown by the prominent deepening of the water table in a narrow zone approximately parallel to the strike of the fault.

At some time, probably before the water table in the Gila conglomerate east of the Miami fault had been lowered by pumping, the water table in the quartz monzonite must have been so high that enough ground water was discharged into Tinhorn Wash to cause at least semipermanent flow southeast of the mine area. This is suggested by terraces of alluvial gravel along the sides of the channel that are firmly cemented by iron oxides and copper carbonates and contain many limestone fragments coated with replacement shells of malachite.

SUPERGENE ENRICHMENT

Although supergene enrichment was a very important agent in the formation of the ore body, its effects are relatively superficial and incomplete. In the few drill holes that have been studied in detail, the depths to which appreciable amounts of chalcocite are present range from 175 to 335 feet or 100 to 220 feet below the leached capping. Even at the top of the chalcocite zone, replacement of chalcopyrite by chalcocite is not complete. Only a few samples showed any replacement of pyrite by chalcocite, and these few contained only an occasional grain of pyrite that showed slight peripheral replacement. Only the smallest grains of chalcopyrite, 0.1 millimeter in diameter or smaller, are completely replaced. All others have cores of unreplaced chalcopyrite that comprise 20 to 80 percent of their sectional area.

From the top of the chalcocite zone, the degree of replacement decreases progressively with depth. There is generally little or no covellite except in the upper part of the enriched zone where chalcocite is being decomposed by acid ferric sulfate solutions formed by action of oxygenated surface waters on residual pyrite. Pyrite is so abundant throughout the deposit that a little remains in the lower part of the leached capping after all the sulfide copper minerals have been destroyed.

Throughout most of the ore body, the amount of acid-soluble copper is generally less than 0.1 percent and rarely exceeds 0.2 percent. The most common occurrence of acid-soluble copper minerals is in the relatively thin chalcocite zone in the granite porphyry bodies.

The top of the chalcocite zone also is the top of the ore body except in a few places where too great a proportion of the copper minerals are oxidized and hence not amenable to recovery by flotation. It is clearly related to the present land surface and reflects most of the topographic details.

The leached capping, which generally contains less than 0.1 percent copper, ranges from 20 to 115 feet in thickness, the average thickness over the ore body is about 65 feet. It is thickest under hills and ridges and is thin under the gulches. The boundary between chalcocite ore and capping is rather sharply defined and shows on the faces of the mine benches as an abrupt change in the color of the rock from light brown to gray.

In most parts of the mine area, the top of the chalcocite zone is well above the present water table (Fig. 3). It approximately coincides with the water

table under the bed of Tinhorn Wash where the ground water level probably is least affected by seasonal and cyclical differences in the amount of precipitation. Much chalcocite occurs below the water table. The decrease in the proportion of chalcocite in depth is gradual, and nowhere does there appear to be an increase in the amount of enrichment at the water table.

Undoubtedly the bottom of the chalcocite zone is very irregular because of the various conditions that affect the circulation of supergene solutions. For example, the amount of enrichment is greatly affected by the host rock. The enriched zone is consistently thinner wherever granite porphyry is the host rock than in the adjacent quartz monzonite. This condition and the generally lower grade of the hypogene metallization in the granite porphyry excludes much of this rock occurring within the mine area from being classed as ore. The result is a hump of marginal or waste material in the central part of the ore body. The same condition prevailed in the granite porphyry at Castle Dome (1, p. 70) but there, fortunately, the bodies were so situated that they did not materially affect mining operations.

The finer texture of the granite porphyry renders it less pervious to circulation of ground water than the quartz monzonite, particularly the coarse-grained facies. This conclusion is confirmed by the higher than normal water table in the granite porphyry bodies and the rock's greater resistance to weathering. It accounts for the relative thinning of the chalcocite zone.

In contrast, the quartz monzonite that is directly adjacent to the granite porphyry masses appears to have been especially pervious, undoubtedly as a result of fracturing and metamorphism attending the intrusion. What little movement of ground water took place in the granite porphyry was largely lateral toward the margins of the bodies as is indicated by the slope of the water table. Probably a large proportion of the copper leached from mineralized granite porphyry was redeposited in the adjacent quartz monzonite.

The drill logs record surprisingly few irregularities in the assay patterns that can clearly be attributed to structural features, and these few are mainly related to contacts. There has been little recognizable deep leaching or oxidation along faults cut by drill holes. The drill sludges are light brown through the leached capping and are uniformly gray through the chalcocite zone to the bottoms of the holes. Intersections of gouge or clay that would indicate major faults are uncommon except in holes that are near the Sleeping Beauty or Coronado fault zones. This condition is in keeping with the few major faults that have been recognized in the outcrops in the mine area.

Age of Supergene Enrichment.—In the western part of the quartz monzonite outcrop, remnants of the dacite volcanic series lie directly on quartz monzonite and granite porphyry (Fig. 1). Farther northeast in the vicinity of the ore body, remnants of dacite overlie the adjacent sedimentary rocks within 400 feet of the Sleeping Beauty fault, which forms the northwest boundary of the quartz monzonite mass. On the northeast margin of the quartz monzonite outcrop near the Miami fault, a patch of dacite overlaps a small outcrop of diabase that intrudes the quartz monzonite. These relationships indicate that at least a part of the quartz monzonite mass had been unroofed before

the dacite eruption, and they strongly suggest that the unroofed area may have been approximately equal to that of the present outcrop.

However, the chalcocite zone of the ore body is clearly related to the present topography carved during the present erosion cycle. Its relative youth is further confirmed by the superficial extent of enrichment and the incomplete replacement of hypogene sulfides by chalcocite.

The quartz monzonite outcrop stood relatively high during the period of exposure that directly preceded the dacite eruption as shown by the absence of Whitetail conglomerate under the dacite in the vicinity of the copper deposit. It appears likely that the mineralized quartz monzonite was undergoing erosion too rapidly to allow sufficient time for oxidation of the hypogene sulfides and the leaching and redeposition of their contained copper.

Furthermore, there is nothing to indicate that the quartz monzonite was again uncovered during the interval between the dacite eruption and deposition of the Gila conglomerate in this area. The lenses of dacite that crop out along the Miami fault zone and the continuous outcrops of dacite that underlie the conglomerate along the west side of Pinal Creek farther to the east suggest that dacite underlies the Gila conglomerate east of the Miami fault. However, a considerable thickness of dacite undoubtedly had been removed by erosion before the Gila conglomerate began to accumulate.

Thus, we may conclude that the enrichment that produced the chalcocite ore of the Copper Cities deposit took place after the block containing the quartz monzonite outcrop had been elevated by displacement along the Miami fault and after the Gila conglomerate and dacite beneath it had been stripped off by erosion that has continued to the present day.

ORE BODY

The shape and size of the Copper Cities ore body is determined to a large extent by economic factors; that is, the tonnage of ore included within the planned limits of the mine is that which can be profitably mined and treated at certain anticipated costs and price of copper. Thus the entirely arbitrary boundaries of the ore body are the ultimate mine limits as illustrated on the cross sections through the mine, Figure 3. The outline of the proposed open-pit mine is shown in Figure 2.

Excluding the leached capping, most of the rock within the mine limits has been affected to some extent by supergene enrichment, and therefore, the mine limits roughly delineate the secondary chalcocite zone. The ore is thin in the granite porphyry bodies where the chalcocite zone is thin and the copper content of the protore below cut-off grade. The ore is generally thick in the quartz monzonite adjacent to the granite porphyry bodies where the copper content of the protore ranged from slightly below to well above cut-off grade, and where the vertical range of supergene enrichment was much greater than in the granite porphyry bodies. Some of the ore near the bottom limits of the mine contains very little chalcocite or none at all. The ore is thick because

the primary copper content of the rock was of ore grade or was so high that it has been raised to ore grade by very slight enrichment.

U. S. GEOLOGICAL SURVEY,
GLOBE, ARIZONA,
Oct. 21, 1953

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GEOCHEMICAL PROSPECTING AT COBALT, ONTARIO[1]

GEORGE F. KOEHLER, P. BLAIR HOSTETLER, AND HEINRICH D. HOLLAND

ABSTRACT

A program of geochemical prospecting was carried out in the summer of 1952 near Cobalt, Ontario. The area in which this work was done lies in the Precambrian shield of Canada, about 320 miles north of Toronto. Much of the area is covered by glacial deposits. The known ore bodies are predominantly thin veins of silver, and nickel and cobalt arsenides found as mesothermal fissure fillings in vertical faults and joints of the area. The cobalt concentration in samples of glacial material, collected on a horizontal and vertical grid over an area of proven mineralization at depth, was determined in order to test the applicability of geochemical prospecting techniques in locating ore bodies in similar situations. A cobalt anomaly in the overburden was located; subsequent drilling proved up mineralization in non-commercial quantities in the bedrock. It is concluded that the present technique is applicable in locating ore bodies where mineralization extends to the bedrock surface in geologic settings similar to those in the Cobalt, Ontario district.

ACKNOWLEDGMENTS

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THE GEOLOGY OF THE COBALT DISTRICT

THE geology of the Cobalt district is typical of the geology of much of the Canadian shield (5, 7, 8).[2] The Keewatin complex, composed in this area predominantly of altered basaltic lava flows, outcrops in many places. The Cobalt Series sediments of probable Huronian age lie on this complex with profound unconformity. These sediments consist of graywackes and coarse

[1] This paper is an abstract of the thesis presented by Mr. Koehler and Mr. Hostetler to the Department of Geology, Princeton University, in partial fulfillment of the requirements for the degree of Bachelor of Arts.

[2] Numbers in parentheses refer to References at end of paper.

conglomerates containing lenses of arkose and quartzite. The Nipissing diabase sill, of Keweenawan age, intrudes both the Keewatin and Cobalt rocks, and is closely associated with their contact. Slightly to the north lie patches of Silurian limestone. Spread over the whole area are Pleistocene glacial and lacustrine deposits of variable thickness.

Intense folding in this area has been confined to Pre-Huronian time. Most of the observable faulting is in the Cobalt sediments and probably took place shortly after the intrusion of the diabase. High and low angle reverse faults with northeast and northwest trends predominate. However, the Lake Temiskaming fault is a normal fault with a maximum displacement of about one thousand feet on which movement occurred in post-Silurian, pre-Pleistocene time. The joint systems show the same trends as the faults.

Ore veins occur as fissure fillings mainly in the joints, but also in some faults. They are relatively narrow, attaining a maximum width of only seven or eight inches. Most of the productive veins, mined in the Cobalt sediments, are nearly vertical and average several hundred feet in length. The most important factor governing the formation of the ore shoots is the diabase sill, and very little ore is found more than three hundred feet from this sill. The contact between Cobalt and Keewatin rocks is an important structural control for ore deposition, whereas the diabase contacts are less important.

The most common vein minerals (4, 8) are the cobalt-nickel-iron arsenides and sulfarsenides, silver, argentite, pyrite, chalcopyrite, bornite, calcite, and quartz. Nickel and cobalt bloom are common on weathered surfaces.

SAMPLING OF THE GLACIAL OVERBURDEN

Geochemical prospecting was carried out in the glacial overburden over the main vein of the Agaunico mine, operated by the Cobalt Consolidated Mining Corp., Ltd., of Cobalt, Ontario. At the 200-foot level the vein is about four to eight inches wide and consists predominantly of cobalt arsenides and sulfarsenides. No silver has been found. Disseminated ore minerals are found in a zone that in a few places reaches a width of eighteen feet.

For geochemical prospecting purposes, a grid was laid out covering an area in which the main vein was expected to crop out. Six grid lines, nine hundred feet long and spaced one hundred feet apart, were cut at right angles to the strike of the main vein over an area in which the vein was expected to reach the surface of the bedrock. Sample stations were established at one hundred foot intervals on the grid lines.

A topographic map, Figure 1, of this area was prepared which was found to be invaluable in the evaluation of the movement of trace elements in relation to the drainage pattern. The variation in elevation on the grid amounted to about one hundred feet. A remnant of Nipissing diabase forms a high ridge in the western portion. The northern portion is covered by fields underlain by glacial clay thicker than twenty feet. The eastern portion is a low, broad valley underlain by glacial materials, mainly clays and sandy clays, and by Cobalt sediments.

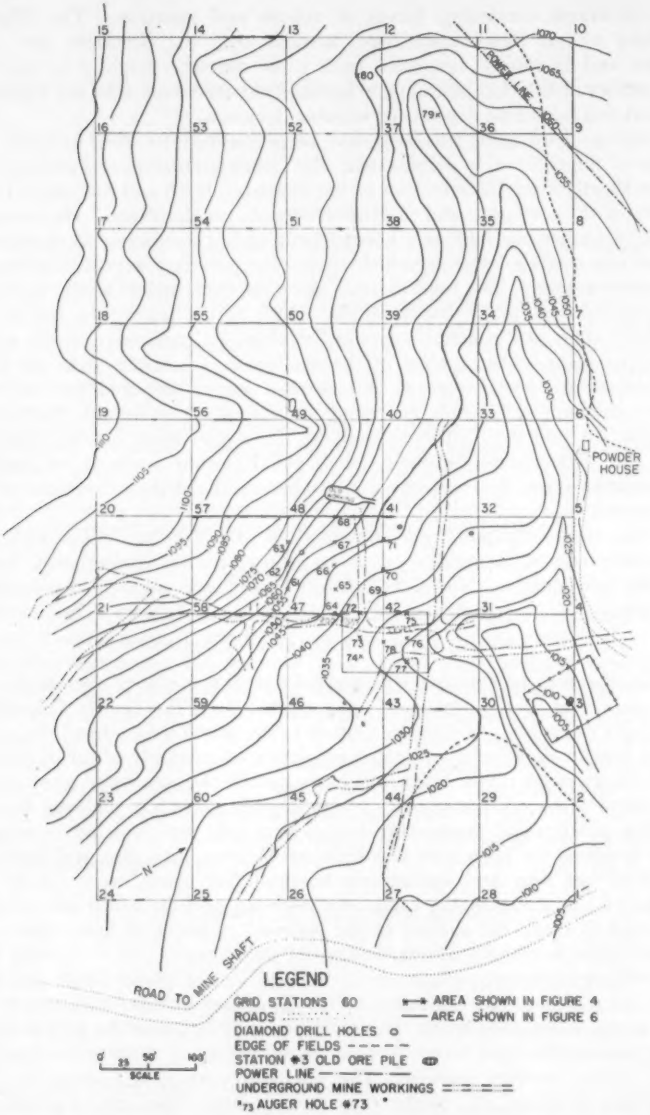

FIG. 1. Topographic map of the Agaunico Mine area.

Soil samples were taken at each sample station, and as the work progressed, at promising intermediate points. At most stations auger holes were sunk to bedrock. Samples of every soil type were taken and, where no change in lithology took place for a depth of more than one foot, sampling was carried out at one foot intervals. Such detailed sampling was necessitated by an almost complete lack initially of information concerning the nature and extent of trace element migration in glacial overburden in this setting. Care was taken to avoid contamination of the soil samples and to obtain representative samples from each soil type. With the use of the tube-like auger [3] of one-inch diameter shown in Figure 2, samples six inches long on the average were obtained on each descent. The samples were packed

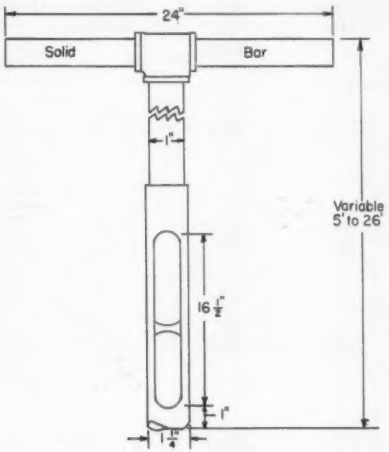

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FIG. 2. Hand auger.

in waxed cardboard containers and taken to the laboratory to be dried and crushed. It was found that in clayey soil with this type of auger, thirty five feet of augering can be completed in an eight hour day.

CHEMICAL ANALYSIS

After having been dried, the soil samples were prepared for analysis by crushing and passing them through an eighty mesh sieve. A 0.1 gram portion of the sample was fused with potassium bisulfate and digested in a hot sodium citrate solution. The resulting solution was filtered and buffered, 2-nitroso-1-napthol was added to form a cobalt complex, which was extracted

[3] Power augers are recommended for further work of this nature.

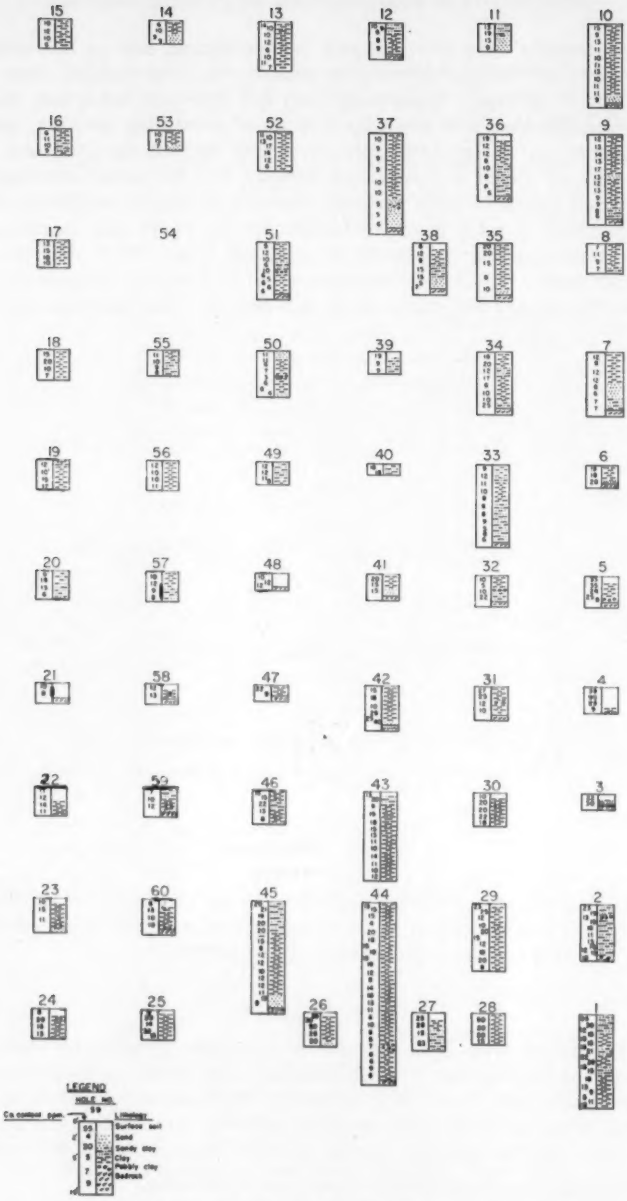

FIG. 3. Lithology and cobalt content of glacial materials in the Agaunico grid area.

with carbon tetrachloride. The extract was shaken with a potassium cyanide solution to form complexes with metals other than cobalt.

The intensity of the color of the cobalt-2-nitroso-1-naphthol complex in carbon tetrachloride was used as a measure of the quantity of cobalt present in the soil or plant sample. These tests are described in detail by Lakin, Almond, and Ward (6) and by Almond (1). Individual analyses were accurate to within ± 30 percent. Between sixty and seventy determinations could be made by two men in an eight hour day.

RESULTS

The lithology and cobalt content of much of the glacial material encountered in augering in the Agaunico grid area are shown in Figure 3, which can be regarded as an overlay on the map Figure 1. The lithologic

TABLE I

COBALT CONTENT OF UNCONTAMINATED GLACIAL MATERIAL

Depth	0′–5′			5′–10′			10′–15′			15′–25′			0′–25′		
	Av.	σ	No. samples	Av.	σ	No. samples	Av.	σ	No. samples	Av.	σ	No. samples	Av.	σ	No. samples
High Area (Elevation above 1045′)															
Surface soil	12.6	2.0	11										12.6	2.0	11
Sand	9.5	1.0	6	6.5	1.0	6	6.2	0.5	4				7.6	1.0	16
Sandy clay	10.0	1.0	18	7.7	0.7	6	6.0		1				9.3	1.0	25
Clay	10.9	2.0	84	9.5	1.5	20	9.0		1				10.6	1.5	105
Low Area (Elevation below 1045′)															
Surface soil	8.5	0.5	4										8.5	0.5	4
Sand															
Sandy clay	17.1	2.0	15	15.2	2.5	6							16.5	2.5	21
Clay	15.6	2.5	27	14.3	4.3	18	10.9	1.0	15	7.8	1.0	10	13.1	3.0	70

classification is only approximate, since all very fine grained sediments were classed as clay, and all sediments intermediate between very fine sediment and sand were called sandy clay.

Sediment samples from the grid area can be subdivided into three groups: those in which the cobalt content has been increased by local surface contamination, those in which the cobalt content has been increased from below due to the exposure of cobalt ore at the bedrock-overburden interface, and those in which the cobalt content has not been increased by either of these two sources of cobalt.

Most of the samples belonged to the third group, and the data on the cobalt content of these samples are shown in Table I. The results of the analyses are here arranged so as to show possible variations due to location, depth, and lithology of the samples. In order to study the effect of topography samples from the grid area were divided into two groups: those from the high area, in which the elevation above sea level was greater than

1,045 feet, and those from the low area, in which the elevation was less than 1,045 feet above sea level. The values of σ were chosen such that the cobalt content of one half of the samples in a given category lies between the average value listed plus σ, and the average value minus σ. It can be seen that, except in the case of the samples of surface soil, the cobalt content of the samples in the low area is significantly higher than that of samples from the high area. The reverse trend in the surface soil samples may be due to the small number of samples in this category. This suggests that move-

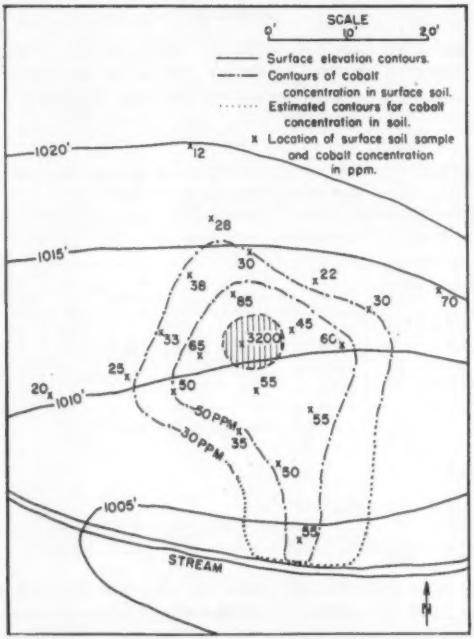

FIG. 4. Topographic map and cobalt dispersion train near ore pile in the vicinity of auger hole no. 3.

ment of cobalt has taken place from the high ground to the low ground. The pronounced decrease in the cobalt content with depth in samples of similar lithology may be in part related to the movement of cobalt from the high to the low area at and above the water table and may also be due to the extraction of cobalt by plant roots followed by the incorporation in the upper soil horizons of cobalt released by the decay of leaves. Surface contamination due to mining activity is not believed to have contributed materially to this trend since the effect of such contamination is found to decrease very rapidly with depth (see below).

In the high area the average cobalt content of sand is less than that of sandy clay, which in turn is less than that of clay. In the low area sand is absent and, in horizons of comparable depth, sandy clay is slightly richer in cobalt than clay. The former situation is probably normal for areas of slight leaching since cobalt is readily adsorbed on the surface of clay particles. The reverse situation in the low area may be characteristic of areas of accumulation, since sandy lenses serve more readily than lenses of clay as channels of cobalt migration from areas of leaching. However, the difference between the average values of the cobalt content of sandy clay and clay in the low area is small and may not be significant.

A detailed study of the dispersion of surface contamination was carried out in the vicinity of a small ore pile near auger hole no. 3. The topography and cobalt content of the surface material are shown in Figure 4. The cobalt content of the soil falls off very rapidly away from the source of contamina-

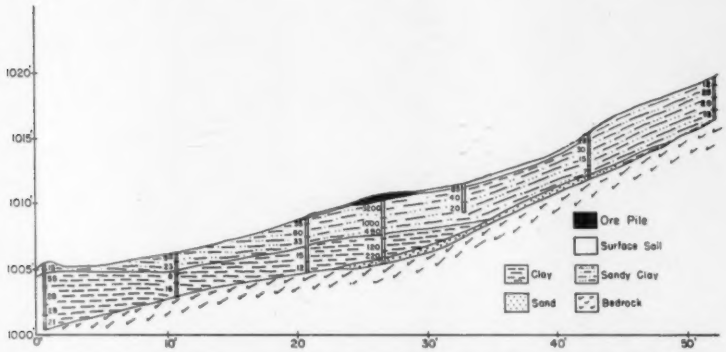

FIG. 5. North-south cross section and cobalt content of glacial materials near ore pile in the vicinity of auger hole no. 3.

tion, and approaches the normal cobalt content of uncontaminated material within 40 feet of the ore pile. The effect of drainage is clearly indicated by the elongation of the dispersion train in the direction of runoff towards the brook. The vertical variation of cobalt values due to contamination from the ore pile is shown in Figure 5, which is a north-south section passing through the source of contamination. The cobalt values drop off rapidly with depth. Only directly beneath the ore pile does the contamination reach bedrock, and at all other sample stations cobalt values equal to those of uncontaminated glacial materials were encountered at bedrock. Since the pile is believed to date from the early part of mining in the area, these results show that the contamination during the operation of the mine has penetrated only a few feet into the glacial material. This conclusion was borne out by studies of dispersion trains near mine roads. In all cases "background"

cobalt values were found at depths greater than 2 feet below the surface. This became a valuable criterion in distinguishing surface contamination from anomalies due to ore exposed at bedrock.

The mode of dispersion of the cobalt suggests the action of rain water passing downward through the contaminated area since downward migration of cobalt below the ore pile far exceeds the degree of lateral migration. Almost complete adsorption of cobalt in solution, probably by clay minerals, is indicated by the lack of lateral dispersion at a depth at which the water responsible for high cobalt values directly beneath the ore pile must have moved and discharged into the brook. Thus diffusion has probably played a very minor role in the creation of this dispersion halo.

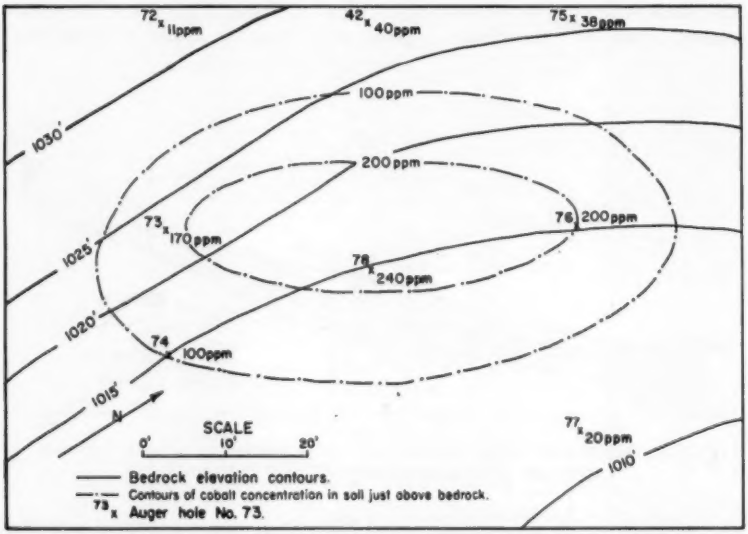

FIG. 6. Topography and cobalt content of glacial material at mineralized bedrock.

One anomaly in which cobalt values were found to increase with depth was located in the grid area. The bedrock elevation contours and cobalt contours at bedrock together with tentative contours of equal cobalt concentration are shown in Figure 6. A cross-section through the center of the anomaly is shown in Figure 7. From these it follows that the anomaly has an elongated, domelike shape. Subsequent drilling proved up seven feet of rock averaging 0.34 percent cobalt [3,400 ppm] beneath the anomaly. This proves that the anomaly is due to the upward migration of cobalt since the deposition of the glacial material. Solution at the bedrock surface and subsequent upward diffusion are suggested by the relative uniformity of the

shape of the anomaly. It is instructive to note that with a sampling interval of 100 feet it would have been easy to have missed the anomaly entirely, but that with the use of a smaller sampling interval surface sampling alone might have been sufficient to locate the anomaly. For subsequent work a sampling interval of 25 or at most 50 feet is suggested if anomalies of this size are sought. In this instance the mineralization proved up under the anomaly was not considered of economic value, and it is possible that anomalies due to ore bodies of economic importance cropping out at the bedrock surface may be large enough to be picked up readily with a larger sampling interval.

That detectable anomalies in non-residual soil are found above certain ore bodies has also been shown by Bischoff (2), who found that copper and zinc deposits studied by him have given rise to geochemical anomalies through

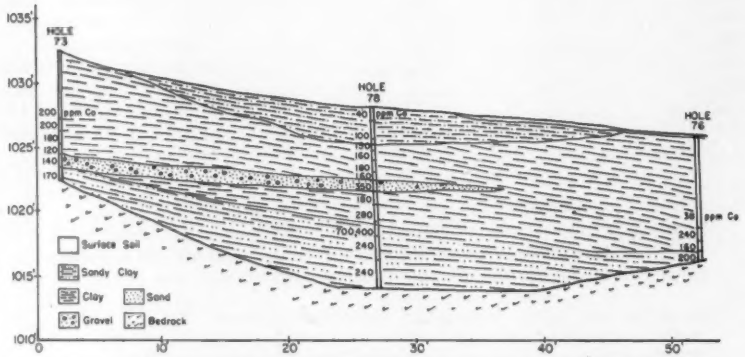

FIG. 7. Cross section through anomaly above mineralized bedrock.

30 to 50 feet of glacial clay and through 20 to 30 feet of fine sand. On the other hand Chisholm (3) using a very mild extraction technique, was unable to detect the presence of excess zinc in glacial clay more than one foot thick overlying ore at Kenora, Ont. Clearly more work is required to determine the conditions favorable for and the best experimental methods of detecting such anomalies. The present example demonstrates that secondary dispersion halos in glacial material of this type can be of sufficient magnitude to be detected by geochemical prospecting methods, and that the techniques outlined above can be used effectively in testing for the presence of ore at the bedrock surface.

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PARAGENESIS OF THE ZINC–LEAD–COPPER DEPOSITS AT THE MINDAMAR MINE, NOVA SCOTIA

K. D. WATSON

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ABSTRACT

The Mindamar mine is in Richmond County on Cape Breton Island, Nova Scotia. The ore bodies are irregular lenses that lie within a persistent, wide, steeply dipping shear zone cutting mainly sericite schist. The schist was derived principally from siliceous siltstone of probable Middle Cambrian age.

The deposits consist of extremely fine-grained pyrite and sphalerite with minor chalcopyrite, galena, and tennantite with a little gold, silver, and realgar in gangue composed mainly of dolomite, magnesite, quartz, sericite, talc, and chlorite. They were formed chiefly in the following overlapping stages:

(1) Deposition of most of the fine-grained pyrite and sphalerite by replacement of sericite schist. (2) Deposition of most of the dolomite and magnesite and some of the quartz, partly in fractures and partly by replacement. (3) Deposition of most of the galena, chalcopyrite, and tennantite and some of the pyrite and sphalerite both in the carbonates and in the fine-grained pyrite- and sphalerite-bearing ore.

Dolomite and magnesite, in part, appear from their textures to be metacolloidal. Talc occurs chiefly as randomly oriented flakes which originated by replacement of dolomite and magnesite without recognizable change in volume.

Most of the numerous diabase dikes were intruded after deposition of the carbonates and ore minerals. Several, however, were emplaced before completion of carbonate and ore deposition and their margins are intensely carbonatized and locally mineralized.

Much of the fine-grained ore shows thin layers differing from one another in the proportions of ore minerals to gangue minerals or of individual ore minerals to each other. This structure may be attributable mainly to selective replacement of relic lamination in sericite schist and partly to replacement controlled by closely spaced parallel fractures.

INTRODUCTION

THE ore bodies at the Mindamar mine are irregular lenses that lie within a persistent, wide, steeply dipping shear zone cutting mainly sericite schist parallel to its foliation. The schist was produced by dynamothermal metamorphism chiefly from very fine siliceous siltstone, and has its foliation parallel to the original lamination in most places. The ore bodies are composed of extremely fine-grained pyrite and sphalerite with minor chalcopyrite, galena, and tennantite in gangue composed principally of dolomite and magnesite, quartz, sericite, talc, and chlorite. The pyrite and sphalerite occur mainly as fine-grained and commonly thinly layered ore formed by replacement of sericite schist. The carbonates and some of the quartz form veins and, to a lesser extent, replacements in some of this mineralized schist and in other rocks. The chalco-

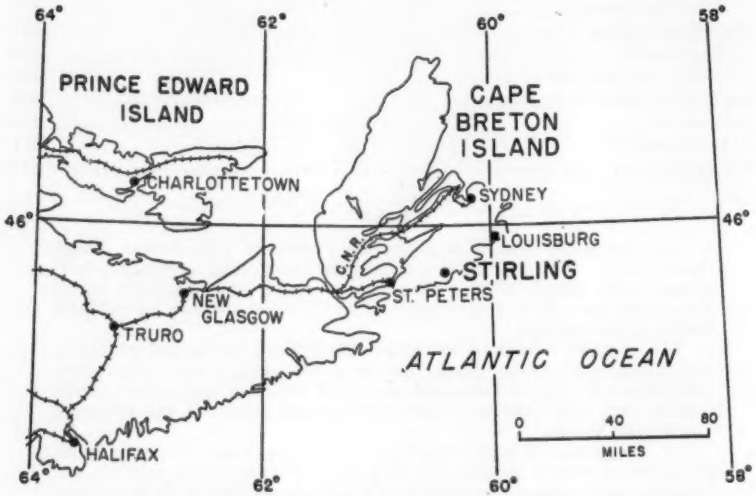


FIG. 1. Key-map of northeastern Nova Scotia showing Stirling where the mine of Mindamar Metals Corporation Limited is situated.

pyrite, galena, and tennantite occur in both the fine-grained pyrite-sphalerite-bearing ore, and the carbonates. Most of the ore bodies consist of intimate mixtures of mineralization that replaced sericite schist and mineralization of carbonates.

The Mindamar mine is an example of an important type of base metal deposit found in metamorphic rocks in several parts of the world. Some features that these so-called massive sulphide deposits have in common are a high content of metallic minerals, extremely fine grain size, relatively simple mineralogy—pyrite, sphalerite, chalcopyrite, and galena being most common—and thinly layered structure in the ore. The Mindamar deposits differ from most of this type mainly by the presence of the abundant dolomite and magnesite.

The deposits present several problems of interest that are considered in this paper. Among these are: the interpretation of the textures of the carbonates; the origin of the locally abundant talc that occurs mainly with the carbonates; the relationships of the ore to the numerous metadiabase dikes in the mine; and the origin of a thinly layered structure that is conspicuous in much of the ore. The geologic structure of the area and the factors localizing ore deposition are beyond the scope of this article. These topics were recently discussed briefly by Richardson (23).[1]

The Mindamar mine, formerly known as the Stirling mine, which is operated by Mindamar Metals Corporation Limited, is in the eastern part of Richmond County on Cape Breton Island, Nova Scotia (Fig. 1). It is connected by roads with the railway at St. Peters and Sydney.

The deposit was discovered in about 1895, it was developed underground initially by the American Cyanamid Company in 1925, and it produced its first concentrates in 1930. From 1927 to 1938, while intermittent operations, which are described by Stevenson (27), were carried on by The British Metal Corporation (Canada) Limited, the mine produced approximately 200,000 tons of ore averaging about 10% Zn, 2% Pb, 1% Cu, and small amounts of silver and gold. In December of 1950, an agreement was made between Mindamar Metals Corporation Limited, then exploring the property, and Dome Exploration (Canada) Limited, whereby the latter would assume management and prepare the property for production. This objective was reached in April of 1952 when a new mill began operating and a new four-compartment shaft had been sunk to the fifth level. At present this shaft extends to a depth of 1,175 feet and the mine produces 560 tons of ore per day containing approximately 6.5% Zn, 1.5% Pb, 0.75% Cu, and small amounts of silver and gold.

GENERAL GEOLOGY

The geology of the region, which has been mapped and described by Weeks (31, 32) and in part by Hutchinson (14), is shown in Figure 2. The oldest rocks, which may be Cambrian or possibly earlier, are predominantly pyroclastics, ranging from felsic to mafic and from coarse breccias to fine tuffs. These are overlain, possibly disconformably, by a relatively thin persistent formation named Morrison River by Hutchinson (14, p. 34) that is composed mainly of conspicuous red micaceous sandstone. The Morrison River formation is succeeded conformably by a group comprising gray and red shale, sandy shale, and argillite that contains Cambrian fossils. A thick formation consisting of pink to gray, fine to conglomeratic quartzite and sandstone may be younger than the Cambrian shales and separated from them by an unconformity. Weeks (32) has suggested that the sedimentary and pyroclastic rocks in the vicinity of Stirling, which are the host rocks for the ore, are possibly younger than map-unit 1 and should not be included in it.[2] Large bodies of granite,

[1] Numbers in parentheses refer to References at end of paper.

[2] In a forthcoming publication of the Geological Survey of Canada, Weeks will include the sedimentary and pyroclastic rocks in the vicinity of Stirling in the Bourinot Group of Middle Cambrian age and the adjacent conglomeratic quartzite and sandstone in the Middle River Group of Silurian or Devonian (?) age.

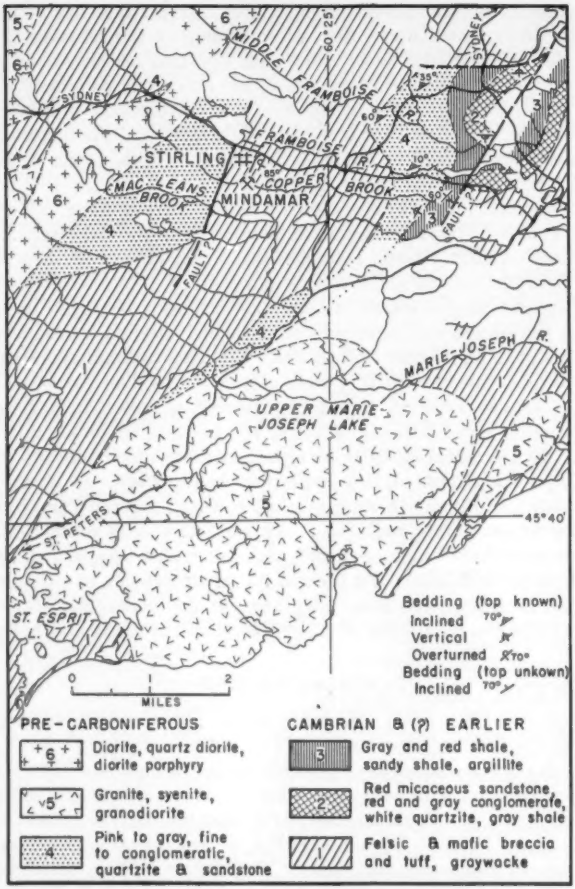


FIG. 2. Geological map of the Stirling area (mainly after L. J. Weeks, 1947).

syenite, and granodiorite of pre-Carboniferous age definitely intrude the Cambrian shales and older pyroclastic and sedimentary rocks and probably intrude the thick formation of quartzite and sandstone as well. Diorite and quartz diorite form large lenticular masses which are younger than the quartzite and probably younger than the granitic intrusives also. Glacial drift conceals the bedrock in most places in the area.

In the vicinity of the Mindamar mine, the sedimentary rock is principally fine siliceous siltstone. This is interlayered with alkali rhyolite and minor

amounts of rhyolite lapilli tuff and graywacke. The rocks strike about N 30° E and dip either vertically or steeply eastward; their tops face westward. They are cut by numerous dikes of altered diabase.

The least altered siltstone is greenish gray or pinkish gray, very hard, aphanitic, and well-laminated rock that fractures conchoidally. It is composed mainly of quartz, alkali feldspar, sericite, chlorite, and cryptocrystalline material. Although the siltstone has been somewhat metamorphosed regionally, it has retained its lamination. The laminae differ from one another in grain size and in proportions of quartz, sericite, and chlorite. Graded lamination, which is common, consists not only of a marked decrease in the size of the relic quartz grains from bottom to top in individual laminae, but also of a concomitant decrease in quartz or chlorite content and increase in sericite content. Although rocks similar to these are commonly named rhyolite tuff in the field, especially in parts of Ontario and Quebec, no convincing evidence was found that these are of pyroclastic origin.

The least altered alkali rhyolite is a light orange or light greenish gray, massive rock having a porphyritic texture and an aphanitic groundmass. The phenocrysts, which compose about 20 percent of the rock, are mainly medium-grained and subhedral. They include corroded quartz grains having the habit of the β-modification, and minor albite. The groundmass is composed mainly of alkali feldspar and quartz, commonly intergrown as spherulites. Minor constituents of the groundmass of some specimens are sericite, carbonates, and chlorite.

In some places, the alkali rhyolite has been highly carbonatized and has become white. The carbonates, which are very fine-grained, have replaced groundmass in preference to phenocrysts and phenocrysts of albite in preference to those of quartz. Thus, alkali rhyolite, consisting of more than 50 percent carbonates, may still clearly show its porphyritic texture.

In a few places, the alkali rhyolite has been chloritized and has become dark greenish gray. In these rocks, the phenocrysts are fractured and bent and are partly replaced by penninite. The groundmass is schistose and consists of abundant penninite and sericite along with quartz, carbonates, alkali feldspar, and leucoxene.

Some of the sheets of alkali rhyolite have brecciated margins, which suggests that they are flows, but others show no criteria for determining whether they are flows or sills.

The rhyolite lapilli tuff occurs as a few poorly stratified lenses in the fine siliceous siltstone. It consists of fragments, mainly subangular and five to ten mm in diameter, in a subordinate fine-grained matrix. Most of the fragments are light gray or pinkish gray, very hard, aphanitic rock that has conchoidal fracture. The matrix is composed mainly of quartz, sericite, and chlorite.

The graywacke, which forms a few thin beds and lenses in the siltstone, is mainly dark greenish gray. Between 25 and 50 percent of the rock consists of quartz and albite of sand grade; the remainder is chlorite, sericite, quartz, feldspar, epidote, and leucoxene of very much finer grade. Some irregular aggregates consisting mainly of quartz and sericite may be altered slate chips.

In a few places, the graywacke has been carbonatized, particularly in the fine-grained matrix, and has become light gray.

Siliceous siltstone, and minor amounts of the associated rocks, have been changed by dynamothermal metamorphism to sericite schist which has its foliation parallel to the original lamination in most places. This schist, which contains the ore bodies, forms a northeasterly striking, steeply dipping zone a few hundred feet wide and at least a few thousand feet long.

The schist is very light gray and commonly of yellowish or greenish hue. In some places, it is rusty-weathering because of the presence of finely disseminated pyrite. The rock is extremely fine-grained and highly schistose. Microscopically, it is seen to consist mainly of quartz and micaceous grains with high birefringence and of smaller amounts of chlorite, albite, and pyrite. Some relic laminae that differ from adjacent ones texturally and mineralogically, and some graded laminae, which have lower parts rich in quartz and upper parts rich in the micaceous grains and very fine quartz, are observable.

Because of the impossibility of distinguishing optically among fine-grained sericite, paragonite, talc, and pyrophyllite, a sample of the schist was analyzed chemically (Table I). The mineral constituents of the sample, in order of

TABLE I

CHEMICAL ANALYSIS OF SCHIST

SiO_2	76.34	MnO	.06	H_2O+	3.14
TiO_2	.18	MgO	4.86	H_2O-	.28
Al_2O_3	11.08	CaO	tr	P_2O_5	.02
Fe_2O_3	.32	Na_2O	.26	CO_2	nil
FeO	1.76	K_2O	1.92	Total	100.22

W. H. Herdsman, *Analyst.*

decreasing abundance, are quartz, micaceous grains with high birefringence, chlorite, albite, and traces of pyrite and goethite. The K_2O content shows the presence of considerable sericite. The low Na_2O content indicates the absence of paragonite because all the soda is attributable to albite. The high MgO content probably cannot be accounted for by chlorite alone and it suggests the presence of some talc in addition. Likewise, the high Al_2O_3 content may not all be attributable to sericite, chlorite, and albite, and may suggest the presence of some pyrophyllite, but without knowledge of the composition of the chlorite or even of the sericite,[3] this is very uncertain. Most of the schist contains little or no carbonate. Locally, however, it has been extensively replaced along fractures and in irregular patches by carbonates.

The zone of schist and carbonates that contains ore has a known length of approximately 3,500 feet. The underground work prior to 1952 was confined to the upper part of what is now called the central body, which is about 1,000 feet long and up to 225 feet wide. A northern body, discovered late in 1951, is more than 800 feet long on the 4th level and up to 80 feet wide. Unlike the central body, which crops out, the northern body reaches only to within about

[3] E.g., Sales and Meyer (24, p. 22) have identified low-alkali sericite at Butte.

200 feet of the surface. In 1952, diamond drilling south of the central body revealed material of ore-grade at a depth of 600 feet which likewise does not extend to the surface.

MINERAL RELATIONSHIPS

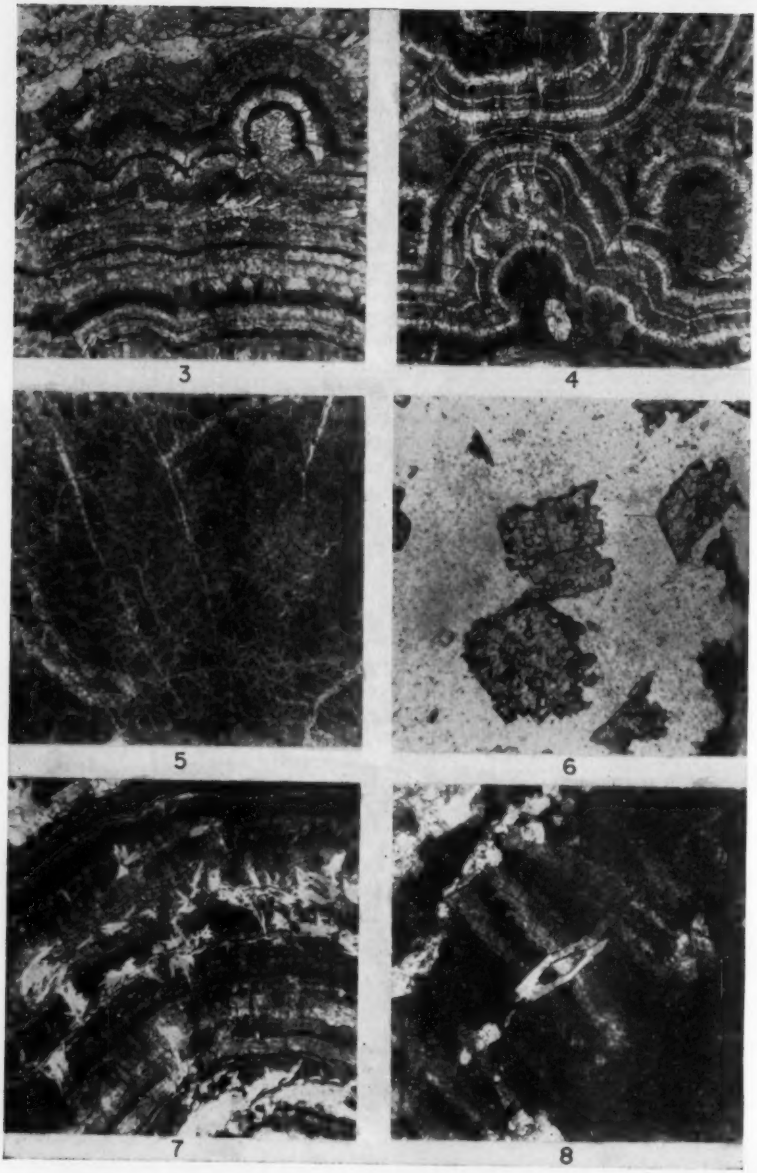
Gangue Minerals.—In order of decreasing abundance, these are dolomite and magnesite, quartz, sericite, talc, chlorite, barite, albite, and alunite. In addition to these, pyrophyllite may be present in small amounts.

Dolomite and magnesite compose approximately one half of the entire ore zone. In some places, the carbonates form numerous, closely spaced, criss-crossing, narrow veins, which are generally sparsely mineralized or barren, that separate small blocks and lenses of carbonatized schist containing ore minerals. In other places, they form large white masses of medium or fine-grain size, which generally contain only minor amounts of other minerals. The carbonates also occur as fine disseminated grains and, where abundant, may impart distinctly lighter colors to the rocks. Some of the bodies of dolomite and magnesite (e.g. the ones shown in Fig. 23) or parts of them contain enough ore minerals—either in blocks and lenses of sericite schist, in the carbonates themselves, or in both—to make them mineable.

The dolomite and magnesite cannot be differentiated without tests.[4] These show that dolomite is more abundant than magnesite and that the two commonly exist in close association. Except for a small amount of dolomite which is light gray, the carbonates are white. They range in grain size from medium to very fine.

Several of the carbonate-rich masses show clearly that, repeatedly, they have been brecciated into angular fragments a few inches across and recemented. Some of the dolomite and magnesite in these masses, and elsewhere as well, appears from its textures to be meta-colloidal. The colloform and syneresis textures, although readily apparent megascopically in places, generally are observed best either microscopically or on etched flat surfaces. The colloform textures include scalloped layers and concentrically layered spheres composed of radially-arranged fibrous crystals (Figs. 3 and 4). Commonly, individual crystals extend across several adjacent layers. Fine veinlets of clear carbonates, which form concentric and radial and polygonal patterns, are abundant in places and give the carbonates a "crackled" appearance (Fig. 5). The fractures occupied by these veinlets are unrelated to any through-going fractures and were probably caused by syneresis. Etched surfaces of colloform carbonates show that dolomite layers are predominant in some specimens, magnesite layers are predominant in others, and alternating layers of dolomite and magnesite occur in a few (Figs. 16 and 18). Some of the colloform carbonates

[4] Chemical tests and the absence of stains on weathered surfaces show that the carbonates are iron-free. The densities of 67 small samples were measured with a Berman microbalance and the compositions corresponding to these measurements were determined from published data (20, 34). The behavior of these identified specimens when tested or etched with HCl was observed and the results were then applied in studying a large number of other carbonate-bearing specimens. The validity of the identification of dolomite and magnesite by this method was confirmed by x-ray spectrometer determinations made by F. Dickson and W. L. Knight of the University of California.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having a predominance of dolomite are traversed by minute veinlets of magnesite and vice versa (Fig. 17).

Fine-grained carbonates have partly replaced all of the rock types found in the vicinity of the ore. These carbonates are most abundant at the margins of several metadiabase dikes and in parts of some alkali rhyolite bodies, where they reach concentrations of 50 percent or more. In the metadiabase, the carbonates have replaced albite in preference to chlorite and in the alkali rhyolite they have replaced groundmass in preference to phenocrysts, and phenocrysts of albite in preference to those of quartz. In much of the siltstone and sericite schist, carbonates are present in only very small amounts but, locally, they form about one third of the rock. In the latter, the carbonates occur as replacement veinlets and large irregular patches of untwinned equant grains which clearly interrupt the schistosity.

The interruption of the schistosity by these veinlets and patches shows that the carbonatization followed the dynamothermal metamorphism. The brecciated carbonate, the few carbonate grains with bent twin lamellae, and the fact that the carbonates are cut by dikes and replaced by talc, both slightly sheared, all show that some movement continued in the shear zone after deposition of the carbonates. Carbonates are cut abruptly by many of the metadiabase dikes, but they intensely replace the margins of several of them and are evidently later than these.

Much of the dolomite and magnesite was deposited after the fine-grained pyrite and sphalerite, which replaced sericite schist in many places to form thinly layered sulphide-rich ore. This is inferred from the numerous veins of carbonates, observable both megascopically and microscopically, that cut this kind of ore. Dolomite was also deposited later than the light gray microcrystalline quartz and the sparse fine-grained pyrite and sphalerite contained by the quartz. This conclusion is based on the observation that the carbonate forms rhomb-shaped porphyroblasts with abundant inclusions of the quartz (Fig. 6) and that irregular patches and veinlets of it definitely interrupt streaks of sulphides in the quartz.

On the other hand, much of the dolomite and magnesite was deposited slightly before most of the galena, chalcopyrite, and tennantite, and some of the pyrite and sphalerite, for the carbonates are replaced, but rarely veined,

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PHOTOMICROGRAPHS

FIG. 3. Colloform textures in carbonates (mainly magnesite, minor dolomite). Randomly oriented white flakes near center are talc. × 20.

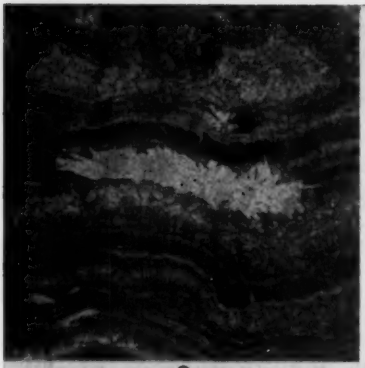
FIG. 4. Colloform textures in carbonates (mainly magnesite, minor dolomite). × 20.

FIG. 5. Dolomite with "crackled" appearance probably caused by syneresis. × 35.

FIG. 6. Porphyroblasts of dolomite with poikiloblastic texture in microcrystalline quartz. × 90.

FIG. 7. Dolomite with colloform textures partly replaced by randomly oriented flakes of talc (white). × 30.

FIG. 8. Talc (white and light gray) formed by replacement of colloform dolomite (dark gray and black) with radial fibrous texture. Crossed nicols. × 90.



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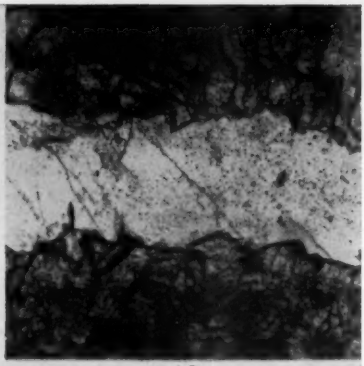

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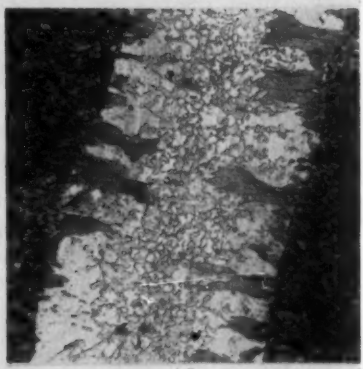

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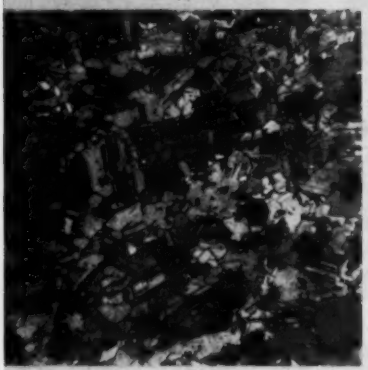

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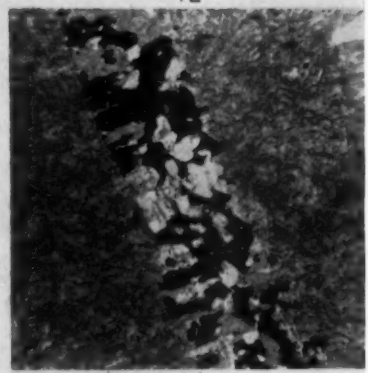

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by these ore minerals. Had these carbonates been deposited long before these ore minerals, movement in the shear zone should have produced fractures in the carbonates in which the ore minerals would have been deposited. A small amount of extremely fine-grained pyrite that forms persistent thin layers in some of the colloform carbonates may be meta-colloidal and contemporaneous with them but most of the pyrite here is associated with irregularly distributed quartz and recrystallized carbonate and is probably later than the colloform carbonates. The carbonates are also replaced by talc and quartz, which show no close relationship to each other, and by traces of barite.

There is no discernible age difference of any significance between the dolomite and magnesite themselves. Commonly, they are intimately associated, and in some colloform material they form alternate layers and also veinlets of one cutting the other (Figs. 16–18).

Talc constitutes probably less than five percent of the ore zone, yet it is conspicuous because of the difficulty it makes in mining and milling. In the mine, some of the talc-bearing rocks cave badly, and in the mill, the talc must be removed by flotation before the sulphides are recovered.

Most of the talc is closely associated with both dolomite and magnesite. Some of it occurs within the carbonates as irregular lenses of pure talc, a fraction of an inch to several inches thick and a few inches to several feet long, and some of it is disseminated in the carbonates as separate flakes and clusters of flakes. A small amount forms randomly oriented flakes in close association with carbonate that has replaced metadiabase. In addition to the talc associated with carbonates, some may be present in sericite schist. This suggestion, however, is based on only one chemical analysis (Table I). The talc that forms the pure masses has a greenish white color and a pearly luster. Commonly, what appears to be lenses of pure talc are found to contain irregular cores of dolomite or magnesite when broken.

Microscopic study of masses of pure talc shows that the flakes are extremely fine-grained and that their orientation is almost entirely random. Adjacent to a shear surface, the talc is slightly schistose. The talc that is disseminated in dolomite and magnesite appears silvery white and it, too, is randomly oriented. Microscopic study of talc in meta-colloidal dolomite and magnesite shows many places where colloform textures such as scalloped layers

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PHOTOMICROGRAPHS

FIG. 9. Carbonate (mainly magnesite) with colloform textures partly replaced by an aggregate of randomly oriented flakes of talc (white). × 25.

FIG. 10. Quartz veinlet in dolomite. Talc is absent. × 90.

FIG. 11. "Pressure shadow" filled mainly with feather quartz, adjacent to pyrite crystal (black) in metadiabase. Crossed nicols. × 90.

FIG. 12. Veinlet in metadiabase, with clinochlore (gray) and quartz (white) at margins and quartz and barite (moderate relief) in middle. × 20.

FIG. 13. Sphalerite showing twin lamellae (light gray to black). Small white blebs are chalcopyrite, gray grains in lower right are quartz. Etched two minutes with HI (S. G. 1.7) at about 50° C. × 170.

FIG. 14. Veinlet in metadiabase, composed of chalcopyrite (black), clinochlore (gray), and quartz (white). × 25.

and concentrically layered spheres with radial fibrous structure have been partly interrupted by talc grains (Figs. 7, 8, and 9).

The manner in which the colloform textures in the carbonates are interrupted by flakes of talc shows clearly that the talc was not deposited contemporaneously with the carbonates nor by fracture-filling, but instead has replaced them. In addition, the absence of disturbance in the delicate textures in the carbonates adjacent to many of the talc grains indicates that the replacement did not result in any significant change in volume. An isovolumetric change from dolomite to talc requires addition of SiO_2, H_2O, and MgO and removal of CaO and CO_2; an isovolumetric change from magnesite to talc requires addition of SiO_2 and H_2O and removal of MgO. It is apparent that the silica necessary for the formation of talc has not been derived from the quartz that occurs in places in the dolomite and magnesite, for there is no tendency whatsoever for the talc and quartz to be closely associated (e.g. Fig. 10). Although a reaction between magnesium-bearing carbonates and quartz to form talc may be possible under appropriate conditions (9, p. 1022), it evidently did not happen in the Mindamar ore bodies.

In a few places, the dolomite or magnesite adjacent to the talc has undergone recrystallization accompanied by an increase in grain size but by no change in chemical composition. It is certain that no calcite has been produced although it has been suggested by Grout (11, p. 481) that it might be expected to form when dolomite is converted to talc.

That the talc originated in an environment essentially free from stress is shown by the conspicuous random orientation of the flakes. Schistose structure is almost insignificant in amount and occurs only where the talc has been sheared after its formation.

Quartz, which composes about 10 percent of the ore, is mostly intimately mixed with the other minerals as very fine grains and hence is inconspicuous. In several places, however, it forms distinct light gray microcrystalline lenses and white medium-grained veins. The lenses are locally mineralized with pyrite and sphalerite chiefly, and are veined by carbonates and replaced by rhomb-shaped porphyroblasts of dolomite (Fig. 6). The white veins commonly cut fine-grained sulphide-rich ore and carbonates and locally they contain medium-grained chalcopyrite and galena. The abundant fine quartz includes mainly relic clastic grains and crystalloblastic grains of the original sericite schist. It also includes clusters of minute grains that have replaced colloform dolomite and magnesite.

Microscopically, many of the pyrite crystals in sparsely mineralized sericite schist and schistose metadiabase show "pressure shadows" (Fig. 11) extended in the direction of schistosity and mainly or entirely filled with feather quartz. As is common elsewhere (19), the elongation of a quartz grain is normal to the pyrite face with which it is in contact.

Quartz, commonly accompanied by barite, chalcopyrite, and pyrite, also forms narrow veinlets in the margins of some of the metadiabase dikes.

Sericite, which, as indicated previously, may also include some talc and pyrophyllite, composes about 10 percent of the ore. It forms fine-grained

lepidoblastic aggregates which appear to be mainly unreplaced parts of the sericite schist.

Chlorite, other than that present in the metadiabase, forms somewhat less than five percent of the ore. It occurs mainly as small flakes in parallel orientation which, like the sericite, are probably relics of the schist.

Barite, which was seen in small amounts in several thin-sections, has two modes of occurrence. In one, it forms clusters of anhedral grains in colloform magnesite and dolomite that locally have been recrystallized or replaced by talc. The barite is considered to be younger than the recrystallized carbonate and talc because some of it contains small irregular grains of these with common orientation that appear to be unreplaced residua. In the other mode of occurrence, barite is present along with quartz, clinochlore, carbonate, albite, pyrite, and chalcopyrite, in veinlets that cut a few of the metadiabase dikes (Fig. 12). The barite and chalcopyrite evidently were deposited last for they occupy the centers of veinlets showing rude crustification.

Alunite was observed in only two thin-sections. It occurs in small amounts in the relatively coarse lower parts of relic graded laminae in sparsely mineralized quartz-sericite schist. It forms aggregates of subparallel elongate grains associated with sericite, quartz, pyrite, and minor sphalerite and tennantite. The alunite probably replaces some sericite and quartz and is about contemporaneous with the pyrite and its accompanying recrystallized quartz.

Metallic Minerals.—In order of decreasing abundance, these are pyrite, sphalerite, chalcopyrite, galena, and tennantite. These are predominantly very fine-grained and commonly intimately associated with one another. The age relationships of all these minerals could not be deduced from polished sections alone because rarely did they show microscopic criteria that were incontrovertible.

Pyrite is abundant. It constitutes about one tenth of the entire mineralized zone and about one fifth of the actual ore. It occurs to some extent in all the types of rock and gangue but it is most plentiful in ore formed by replacement of sericite schist.

Most of the pyrite grains are subhedral cubes and pyritohedrons; some, however, are euhedral and some are anhedral. In general, the grains are extremely fine, most of them being in the range between 0.1 and 0.01 mm in diameter. A complete analysis of the grain sizes made by Haycock (13, p. 81–84) shows clearly that not only the pyrite but also the other ore minerals are mostly very fine.

In polished sections, many of the pyrite crystals are anisotropic and show blue-gray and orange-brown polarization colors. Anisotropism in pyrite has been attributed to the insertion of excess iron atoms in the crystal in a regular manner, rather than at random (26, p. 12).

Pyrite was apparently deposited throughout the entire period of mineralization. The earliest pyrite formed euhedral and subhedral crystals replacing sericite schist. Subsequently, many of these crystals were highly corroded by sphalerite and, to a lesser degree, by chalcopyrite and galena. Some of the pyrite crystals are also veined by sphalerite, chalcopyrite, galena, tennantite, and carbonate. A little of the pyrite present in the carbonate masses

may have been deposited contemporaneously with them but most of it formed later by replacement. The latest pyrite occurs in a few of the numerous metadiabase dikes that cut the ore bodies.

Sphalerite generally composes from 10 to 15 percent of the ore. Most of it occurs in ore that was formed by replacement of pyrite-bearing sericite schist. It is brownish black and extremely fine-grained except for a small amount in carbonates that is yellowish gray and almost medium-grained. The grains are anhedral and have regular twin lamellae (Fig. 13); they contain no exsolution bodies of chalcopyrite.

Most of the sphalerite seems to be a little younger than the abundant pyrite in the sericite schist and older than the majority of the chalcopyrite, galena, tennantite, and carbonates. It commonly forms a matrix for pyrite crystals and it appears to have corroded the margins and, to a lesser extent, the interiors of these crystals.

Chalcopyrite makes up about three percent of the ore. Most of it is closely associated with galena, with which it displays "mutual" boundaries. It is abundant in some layers of the fine-grained sulphide-rich ore that was formed by replacement of sericite schist. It is also conspicuous in some of the bodies of carbonates that are later than much of the pyrite and sphalerite. Here it occurs as clusters of relatively large irregular grains along with galena and minor tennantite. Some chalcopyrite forms veinlets that cut the layered fine-grained ore (Fig. 19). A small amount of it occurs in veinlets in the margins of a few of the numerous metadiabase dikes that cut the ore bodies.

It appears that most of the chalcopyrite was deposited after most of the pyrite and sphalerite, slightly after most of the carbonates, and simultaneously with most of the galena and tennantite.

Galena composes from one to two percent of the ore. It generally forms irregular grains closely associated and apparently contemporaneous with chalcopyrite and tennantite. In a few places, galena occurs as films on chlorite in the schistose margins of metadiabase dikes.

Tennantite,[5] which composes less than one percent of the ore, is visible megascopically in only a few places. Most of it is present as microscopic grains that have "mutual" boundaries with galena and chalcopyrite. That which is visible megascopically occurs either with chalcopyrite and galena in carbonates or alone in talc.

Like chalcopyrite and galena, tennantite apparently was deposited after most of the pyrite and sphalerite and slightly after most of the carbonates.

Silver and *gold* are present in small amounts in the ore, the average grades being approximately two and 0.03 ounces per ton respectively. Spectrograms of samples of galena and tennantite drilled from polished sections show strong traces of silver (13, p. 80–81). Ore dressing tests confirm this distribution of silver, for there is a close correlation between silver content and lead and arsenic content of concentrates (15).

[5] Identification based partly on spectrographic analyses. Visual estimates of line intensities made by Haycock (13, p. 80–81) and comparisons of measured intensities in spectrograms of the mineral and standards, made at the University of California, show arsenic to be more abundant than antimony.

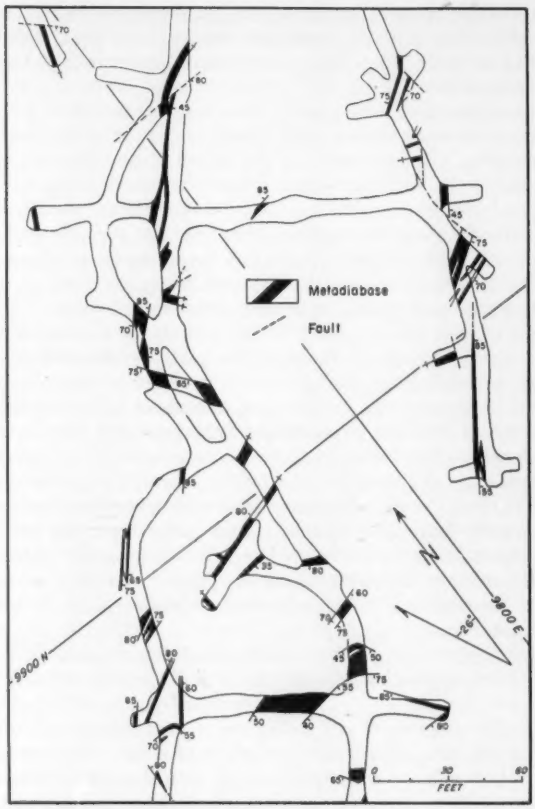


FIG. 15. Plan of a part of the 2nd-level where metadiabase dikes are numerous.

The gold has never been observed in the ore. Assays of zinc concentrates show that it is not closely associated with sphalerite.

Realgar occurs in a very small amount and in only one locality. It partly fills a few minute fractures in the dolomitized margin of a highly chloritized metadiabase dike exposed on the 3rd level. These realgar-bearing fractures are probably younger than ones filled with quartz, carbonate, pyrite, and barite which occur at the same locality.

METADIABASE DIKES

Description.—Dikes of altered diabase, which have various attitudes and sizes, are numerous in many parts of the ore zone as is shown in Figs. 15 and

23. Their strikes range from parallel to perpendicular to that of the shear zone, their dips from vertical to nearly horizontal, and their widths from less than a foot to about 75 feet. Most of the dikes, however, dip steeply and are only a few feet wide.

Very few of the dikes now display their original textures clearly; instead, the majority of them are considerably altered and show predominantly crystalloblastic textures. The structure of the dikes ranges from massive to distinctly schistose; the latter structure is fairly common along the margins of the dikes, particularly those that tend to be parallel to the shear zone.

Most of the dikes cut the carbonates and the ore abruptly and are neither carbonatized nor mineralized. Several of them, however, show intense replacement by carbonates at their borders, and several of them are cut by veinlets of chalcopyrite and pyrite, or contain disseminated pyrite.

The least altered diabase found in the vicinity of the ore deposit occurs along the northwestern side of the large dike partly shown in Figure 23. The rock is dark greenish gray, fine-grained with distinct relic diabasic texture, and massive. Albite (ca An_2) which composes about half of the rock occurs as randomly-oriented euhedral to subhedral laths generally ranging from 0.5 to one mm. in length. The interstices between these laths are occupied by uralite, penninite, epidote, and ilmenite. The uralite, constituting from one fourth to one third of the rock, forms subhedral prisms with frayed borders ranging from 0.5 to one mm in length. Penninite, which makes up 5–10 per cent of the rock, is closely associated with the epidote, which is generally present in somewhat smaller amount, and with traces of sphene. Ilmenite composes about 5 percent of the rock and forms subhedral skeletal crystals that are slightly altered to leucoxene.

The original pyroxene of the diabase was evidently changed entirely to uralite and, later, approximately one third of the uralite formed aggregates of penninite and epidote which contain traces of sphene. The albite contains no relics of calcic plagioclase nor inclusions of any calcium-rich mineral such as epidote, calcite, etc. One must conclude that if the albite were formed by replacement of an original calcic plagioclase, both the albitization and the removal of the calcium from the original plagioclase grains were absolutely complete.

Megascopically, the schistose diabase differs from the least altered type of diabase described above, not only in its structure but also in the presence of abundant chlorite, of numerous minute yellowish brown irregular grains of leucoxene, which are particularly noticeable in wet drill cores, and of conspicuous discontinuous films of hematite on joint surfaces. Microscopic study of schistose specimens from the southeastern side of the large dike (Fig. 23) shows that the relic diabasic texture has been supplanted entirely by a crystalloblastic texture. All the uralite has been converted to very fine-grained penninite, which has parallel orientation and is mainly responsible for the schistosity of the rock. The albite has recrystallized to form xenoblastic grains of smaller size but has not changed its composition. All the ilmenite crystals have been altered to irregular lenticular aggregates of leucoxene. In addition to these changes, which are regarded as effects of dynamothermal meta-

morphism, some later replacement by carbonates, talc, and quartz has occurred.

Microscopic study of a slightly schistose dike exposed on the 4th level showed it to be intermediate between the two types described above. It was composed entirely of fine-grained albite, chlorite (in this case, clinochlore), and minor leucoxene and yet it retained a vague relic diabasic texture.

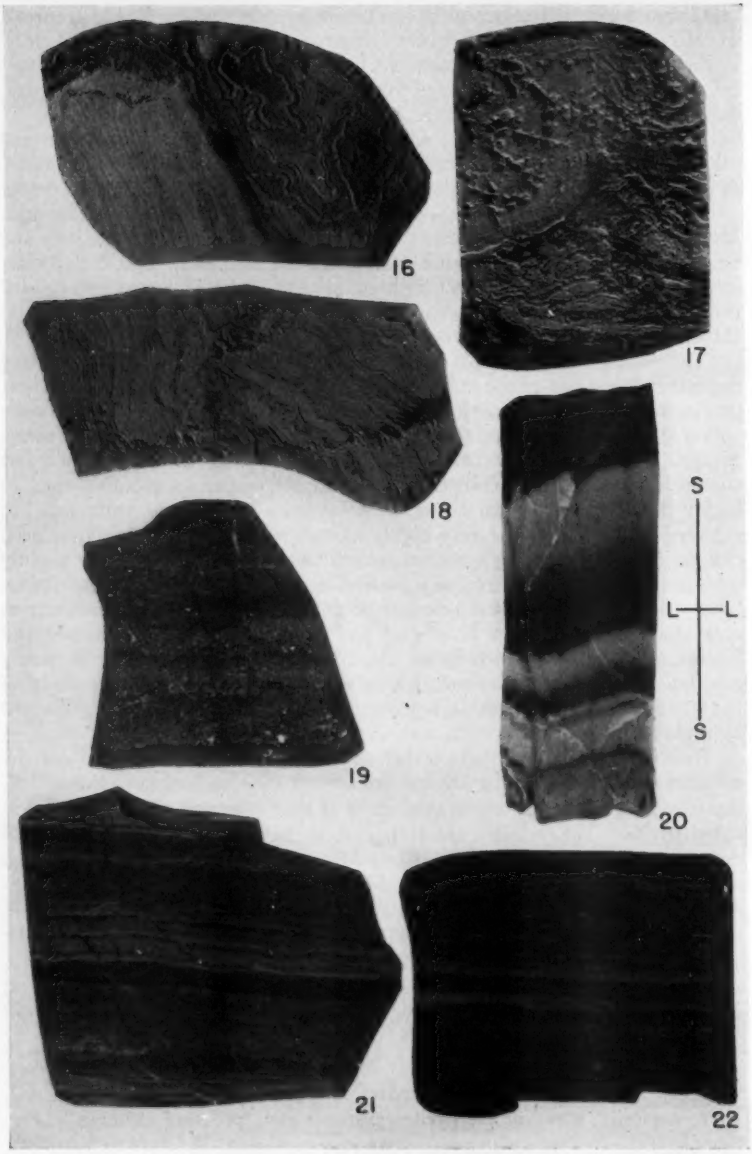
A large relatively unaltered albitite dike, which shows some textural and mineralogical similarities to the metadiabase, is exposed underground south of the No. 1 shaft. The middle of the dike is pink and fine-grained and consists mainly of randomly oriented laths of albite containing hematite dust. Minor quartz, penninite, epidote, and hornblende and traces of leucoxene and magnetite occupy small polygonal spaces between the laths. The chilled margins of the dike are light greenish gray and consist of a few pseudomorphs of penninite after pyroxene in a microcrystalline to cryptocrystalline groundmass showing flow layers.

The most noticeable result of the intense carbonatization that has affected the margins of some of the metadiabase dikes is lightening of color. For example, some dikes range from pale olive (10Y 6/2)[6] at the edge through dusky yellow green (5GY 5/2) to dark greenish gray (5G 4/1) a few inches away. Most of the highly altered rocks contain about 50 percent carbonate, but a few contain as much as 80 percent. The carbonate occurs as rhomb-shaped to highly irregular grains and is mainly dolomite. Most of the carbonate has replaced albite, but, in the very highly altered rocks, some of it has replaced chlorite as well. Typical specimens of carbonatized metadiabase are slightly schistose because of the roughly parallel orientation of the chlorite flakes. They consist of about equal amounts of dolomite and chlorite (penninite in some dikes and clinochlore in others) and minor amounts of albite, talc, and leucoxene. The talc, which forms flakes with random orientation, is closely associated with the dolomite and, in view of the conclusion reached by studying the talc-carbonate relationships in other parts of the deposit, it probably formed by replacement of the dolomite.

Relationships to Ore.—As stated previously, most of the dikes cut the carbonates and the ore abruptly and are neither carbonatized nor mineralized, but several of them do contain veinlets of chalcopyrite and pyrite or disseminated pyrite. The veinlets are restricted to the schistose margins of both carbonatized and uncarbonatized dikes. Rarely do they exceed one half inch in width or a few feet in length. In addition to sulphides, most of them contain quartz, clinochlore, barite, and carbonate and a few of them contain a small amount of albite (Figs. 12, 14). In some veinlets, the margins consist largely of quartz and clinochlore with comb structure and the centers largely of barite and chalcopyrite. The sequence of deposition, deduced from several veinlets, shows considerable overlapping, with clinochlore, quartz, and pyrite early, carbonate and albite intermediate, and barite and chalcopyrite late.

The disseminated pyrite, which is abundant in the margins of some dikes, generally forms euhedral and subhedral cubes less than a millimeter in size. Microscopically, many of the pyrite crystals show "pressure shadows" (Fig.

[6] Symbols are those of the Rock-Color Chart (10).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11) extended in the direction of schistosity, and filled with feather quartz and minor chlorite.

In addition to the mineralization described above, galena occurs as films on chlorite in the schistose margins of a few dikes and realgar occurs in the carbonatized margin of one dike exposed on the 3rd level.

The writer is aware that in the problem of determining the relative ages of dikes and ore, the significance of abrupt cross-cutting relationships of dikes or of the presence of sulphides within dikes is controversial. At the Horne mine in the Noranda district of western Quebec, for example, a large diabase dike that cuts the ore zone generally displays sharp chilled contacts adjacent to the ore, yet, in some places, it is penetrated by chalcopyrite and lesser amounts of other sulphides. These offshoots from the ore bodies reach three feet in width and extend into the diabase for as much as eight feet. Price (21, p. 138) has noted that the ore bodies on opposite sides of the dike do not match perfectly, as they would had a single ore body been cut by the dike. Interpretations of this somewhat conflicting evidence have been given by Cooke, James, and Mawdsley (6, p. 197 and p. 204–205), Price (21, p. 138–140; 22, p. 772), Suffel (29), Wilson (33, p. 76–81), Brown (3, p. 691), and others. Some suggest that the diabase dike was intruded after the deposition of some of the sulphides but before the deposition of the chalcopyrite. Some consider the possibility that the entire mineralization is earlier than the dike and that the chalcopyrite, and, to a lesser extent, the other sulphides were slightly redistributed after the intrusion. Wilson, however, rejects this as an explanation of the origin of the large sulphide masses that penetrate the dike and favors the hypothesis that all the ore was deposited after the diabase was intruded. Suffel, who has also reached this conclusion, believes that the diabase dike resisted replacement because of its impervious chilled margins.

A similar problem exists at the Normetal mine in Desmeloizes township, northwestern Quebec. There, too, a large body of diabase, called the Abana dike, generally has chilled margins in contact with the ore, yet it is penetrated by sulphides in places. Small stringers of chilled diabase cutting the massive sulphides extend for some distance from the main dike. Locally, the contact between diabase and sulphides is very irregular and the chilled edge is fretted by chalcopyrite. Wilson (33, p. 79) has suggested that the intrusion of the

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FIG. 16. Colloform textures in dolomite (deeply etched) and magnesite (unetched). × 1.

FIG. 17. Veinlets of magnesite (unetched) in colloform dolomite. × 1.

FIG. 18. Alternating layers of dolomite (etched) and magnesite (unetched) showing colloform textures. Dolomite has replaced magnesite in irregular patches. × ⅘.

FIG. 19. Thinly layered sulphide-rich ore. White veinlet at right is carbonate; diagonal one at left is chalcopyrite. × 1.

FIG. 20. Slab of sparsely mineralized sericite schist cut normal to the schistosity (S—S) and to relic graded lamination (L—L), which are approximately normal to one another. Pyrite (small white grains) is concentrated in the lower parts of graded laminae, not along surfaces of schistosity. × 1.

FIG. 21. Lamination in siliceous siltstone. × 1.

FIG. 22. Thinly layered sulphide-rich ore. Lightest colored layers contain abundant chalcopyrite. × 1.

diabase preceded the entire mineralization but Mawdsley (16, p. 67–68), Brown (3, p. 690–691), and Tolman (30, p. 23–25) have drawn the opposite conclusion. Brown interprets the penetration of the dike by chalcopyrite as an effect of the intrusion of the diabase that caused the chalcopyrite close to the dike to become redistributed. He supports this interpretation by citing experiments of Hawley (12) which show that pyrite, pyrrhotite, or chalcopyrite can become mobile at low temperatures and enter fractures in other minerals.

Evidence for the mobilization of chalcopyrite adjacent to an intrusive at the Eustis mine in southeastern Quebec has been described by Stevenson (28, p. 352–362). There, a camptonite dike 40 feet thick has dense borders, and occupies a fault that slightly displaces an ore body composed mainly of pyrite and chalcopyrite. The dike has metamorphosed the ore for a distance of approximately ten feet from its contacts to an aggregate in which pyrrhotite, cubanite, and anthophyllite predominate. Chalcopyrite, believed to be material redistributed during this metamorphism, penetrates the margins of the dike but for only a quarter of an inch.

At the Mindamar mine, the fact that most of the dikes cut the ore sharply and are unmineralized probably means that most of them are later than the ore. The sulphides contained in some of the dikes may represent material either slightly redistributed by the intrusions or derived from a remote source. The absence of sulphides in the largest dikes, which should have been capable, had any of them been, of mobilizing some of the adjacent sulphides, makes the suggestion of a local source the less likely one. The alternative, that a small amount of allocthonous sulphides along with a few other minerals were deposited after emplacement of some of the dikes, would be in accord with the observation that the sulphides occur in the most altered and presumably oldest dikes. It would also agree with the fact that the sulphides in the dikes are mainly chalcopyrite and pyrite which are minerals that continued to be deposited until late in the formation of the ore bodies.

LAYERED STRUCTURE OF ORE

Layering [7] is evident in much of the ore that contains abundant fine-grained sulphides (Figs. 19, 22). Adjacent layers differ greatly in the proportions of ore minerals to gangue minerals or in the proportions of individual ore minerals to each other. Specifically, layers rich in fine-grained pyrite and sphalerite alternate with those rich in sericite or sericite and quartz, layers rich in chalcopyrite alternate with those rich in pyrite and sphalerite, and layers rich in sphalerite alternate with those rich in pyrite. Layering resulting from the first condition is much more common though less conspicuous than that resulting from the others.

The layers range from about one half millimeter to a few millimeters in thickness for the most part. This range is similar to that of the laminae of the siliceous siltstone (cf. Figs. 21 and 22). Many individual layers in the ore are fairly extensive and uniform in thickness but some of them lack persistence.

[7] Commonly called "banding." See Calkins (5) for discussion of these terms.

Where layered ore is adjacent to sericite schist, the layering is parallel to the relic lamination in the schist. Inasmuch as the schistosity in almost all places is also parallel to the lamination, the layering and schistosity are generally parallel (Fig. 23).

Thin layering is common in ore deposits rich in fine-grained sulphides. This structure might result from preservation of original foliation or lamina-

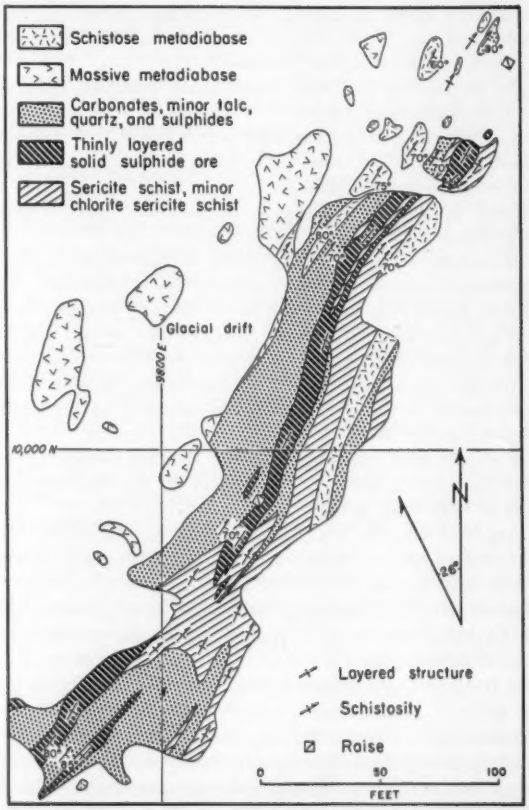

FIG. 23. Surface plan of part of ore body showing parallelism between layered structure in solid sulphide ore and schistosity in sericite schist.

tion during replacement, from deposition of ore minerals in closely spaced parallel fractures, from mylonitization, from gliding and recrystallization flowage, from metamorphic differentiation, or from combinations of these (1, p. 110–112; 2, p. 13–20; 7, p. 45; 8, p. 26–31; 17, p. 409; and 18 for examples of some of these).

In the Mindamar ore deposits, the structure, consisting of alternating sulphide-rich and gangue-rich layers, has probably been inherited from relic lamination in sericite schist. Much of the sericite schist has relic laminae which are relatively rich in either quartz or sericite, or which grade from quartz-rich bottoms to finer-grained sericite-rich tops. Where the sulphides are present in only small amounts, they tend to replace only the laminae or parts of laminae in which quartz is plentiful. More complete replacement produces sulphide-rich layers apparently representing coarser laminae and lower parts of graded laminae, alternating with sericite-rich layers representing finer laminae and upper parts of graded laminae.

That relic lamination has been much more effective than schistosity in localizing the deposition of the early sulphides is shown in the few places where these structures intersect at high angles. On the 2nd level, south of the No. 1 shaft, for example, where schistosity cuts relic lamination at a high angle on the crest of a small fold, it is clear that the pyrite in the sparsely mineralized rock is concentrated mainly in the lower parts of graded laminae and not alorg planes of schistosity (Fig. 20).

Layers containing abundant chalcopyrite alternating with those containing abundant pyrite and sphalerite require additional explanation. It may be that the chalcopyrite, which was among the last of the ore-minerals to be deposited, replaced the gangue-rich layers more readily than it did the sulphide-rich layers. Perhaps this selectivity was due in part to the presence of shear planes that allowed the ore fluid to enter. Certainly, such fractures, resulting from late movement in the shear zone, are common in the highly schistose sericite-rich parts of the ore.

A similar explanation may apply for the layering consisting of pyrite-rich and sphalerite-rich layers and it is in accord with the conclusion that some of the sphalerite is later than pyrite.

There is no evidence that any of the layering is attributable to gliding and recrystallization flowage or metamorphic differentiation and there is evidence that it is not attributable to mylonitization. Etched surfaces reveal no strained sphalerite like that shown by Butler (4, Figs. 8, 9) and Schneiderhöhn (25, Fig. 112) but, instead, only sphalerite with undeformed twin lamellae (Fig. 13; cf. Schneiderhöhn, Figs. 60, 61, 62). Furthermore, they show only an occasional fractured and veined crystal of pyrite, no highly shattered and "strung out" grains. The fineness of much of the ore evidently is not a result of mylonitization but of replacement of a very fine-grained rock.

The conclusion that the sulphides are free from the effects of severe deformation does not conflict seriously with the observation that some of the diabase dikes cutting the ore have schistose margins. It is probable that the movements occurring in the shear zone after deposition of most of the sulphides would take place predominantly in the highly schistose sericite-rich folia, not in the massive sulphides.

CONCLUSIONS

The minerals identified in the Mindamar ore, in approximate order of decreasing abundance, are dolomite and magnesite, pyrite, sphalerite, quartz,

sericite, talc, chlorite, chalcopyrite, galena, tennantite, barite, albite, alunite, and realgar.

The mineral deposits were formed mainly in three overlapping stages as follows:

(1) Deposition of most of the fine-grained pyrite and sphalerite by replacement of sericite schist derived by dynamothermal metamorphism chiefly of siliceous siltstone.

(2) Deposition of most of the dolomite and magnesite and some of the quartz, partly in fractures and partly by replacement.

(3) Deposition of most of the galena, chalcopyrite, and tennantite and some of the pyrite and sphalerite both in the carbonates and in the fine-grained pyrite- and sphalerite-bearing ore formed by replacement of sericite schist.

The dolomite and magnesite, in part, appear from their textures to be meta-colloidal for they form scalloped layers and concentrically layered spheres which are commonly "crackled."

Most of the talc was formed by replacement of dolomite and magnesite. The replacement was not accompanied by any noticeable change in volume, it occurred in an environment essentially free from stress, and it was unrelated to the presence of quartz.

Most of the numerous diabase dikes were intruded after the deposition of the carbonates and the ore minerals. Several of them, however, have intensely carbonatized and locally mineralized margins, and were probably emplaced before the completion of carbonate and ore deposition.

The ore that is rich in fine-grained sulphides commonly is composed of thin layers differing from one another in the proportions of ore minerals to gangue minerals or in the proportions of individual ore minerals to each other. This structure is probably a result of selective replacement acting on relic lamination in sericite schist; perhaps also, and to a lesser extent, of replacement controlled by closely spaced parallel fractures.

ACKNOWLEDGMENTS

This article is based on a field study of the central body carried on for three months during the summer of 1951 and on laboratory work, which included a study of about 100 thin sections and polished surfaces, carried on subsequently at the University of California.

The writer is grateful to the late Mr. J. G. McCrea, President and General Manager of Mindamar Metals Corporation Limited, for cooperation in this study and for permission to publish the results, and to the University of California for funds for the chemical analysis. He also wishes to thank Mr. A. C. Daley, Dr. D. Carlisle, Mr. P. W. Richardson and Dr. George Tunell for their valuable assistance. Dr. B. J. Keating kindly made available reports on the property written by R. F. Cormier, J. J. Dunn, and R. J. Wallace, students at Saint Francis Xavier University at Antigonish, Nova Scotia.

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LAND-SURFACE SUBSIDENCE AND ITS RELATION TO THE WITHDRAWAL OF GROUND WATER IN THE HOUSTON-GALVESTON REGION, TEXAS[1]

A. G. WINSLOW AND W. W. DOYEL

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ABSTRACT

Leveling by the United States Coast and Geodetic Survey in 1951 showed a general land-surface subsidence in the Houston-Galveston region, Texas, since previous leveling in 1943. The region of subsidence coincides with a region of large-scale ground-water withdrawals where the water is pumped from a series of unconsolidated sands interbedded with clay layers. In the northern part of the region the ratio of land-surface subsidence to decline in artesian pressure head is about 1 to 100. In the southern part of the region, where there is a greater percentage of clay in the section, the ratio is greater. The subsidence is attributed to compaction of the clays as the artesian pressure in the sands is reduced. From a comparison of the volume of subsidence to the volume of water pumped, it appears that about one-sixth of the water pumped has been supplied from storage in the clays.

INTRODUCTION

THE Houston-Galveston region, as discussed here, includes Harris and Galveston Counties and parts of Brazoria, Chambers, Fort Bend, Liberty, and Montgomery Counties, Tex. The region lies on the Gulf Coastal Plain of Texas and consists of a nearly flat plain rising from sea level at the Gulf of Mexico to a maximum altitude of 318 feet in northwestern Harris County. The slope of the land surface, however, is not uniform, the area between the Gulf Coast and Houston being much flatter than the inland part.

The region contains the most heavily industrialized areas on the Texas Gulf Coast, and in 1950 it contained about 13 percent of the total population of the State of Texas, although containing only 1.5 percent of the land area.

[1] Publication authorized by the Director, U. S. Geological Survey.

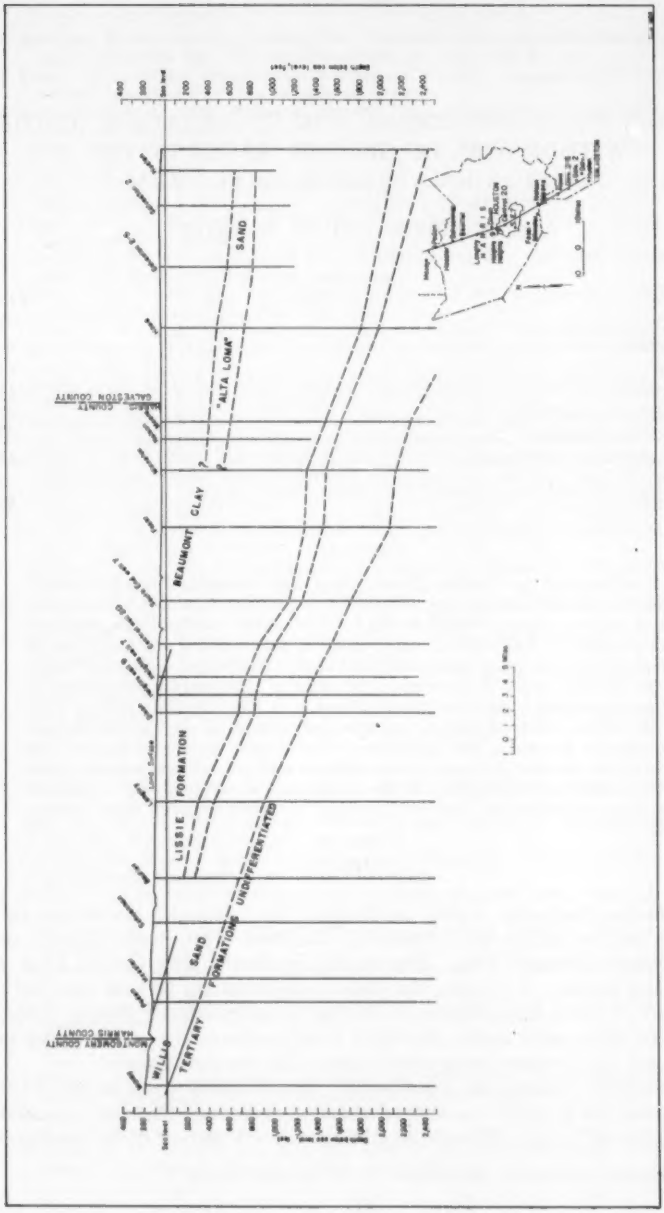

FIGURE 1. Cross section from southern Montgomery County to the vicinity of Alta Loma, Galveston County, Texas

FIG. 1.

Most of the industry and population and much of the rice irrigation in the region is dependent on ground water for its water supply, and during 1952 a total of about 330 million gallons of water a day was pumped from wells.

This study is a part of the investigation of the ground-water resources of the Houston area by the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers and the City of Houston. The authors are grateful to Dr. M. King Hubbert of the Shell Oil Co. for suggestions which were helpful in the preparation of this paper.

GEOLOGY

The geology of the Houston-Galveston region as it applies to the occurrence of ground water has been described by a number of authors. The description by Lang and Winslow (3)[2] is summarized here in order that the relationship between subsidence and the withdrawal of ground water may be shown.

The Houston-Galveston region is on the Gulf Coastal Plain of Texas and is underlain by a thick series of Tertiary and Quaternary deposits. The sediments consist mostly of unconsolidated sands and clays dipping gently toward the coast. The dip of the beds is greater than the slope of the land surface and successively older formations crop out toward the interior. The presence of this typical coastal-plain type of structure, together with the occurrence of relatively impermeable layers of clay interbedded with and overlying the sands, result in conditions favorable for the occurrence of artesian water.

The geologic formations that supply most of the water to wells in the region are the Willis sand of Pliocene (?) age and the Lissie formation, Alta Loma sand of Rose (7), and Beaumont clay of Pleistocene age. The Lissie and Willis have not been separated in the subsurface and are considered a single aquifer. Figure 1 is a cross section across Harris County and part of Galveston County based on electrical logs of oil tests and water wells.

The Lissie and Willis formation, which have a maximum combined thickness of about 2,200 feet in the region, are composed of unconsolidated sands and clays in which the sands predominate, especially in the lower part. The sands are lenticular and fine to coarse grained. The clay beds are more continuous and may be traced greater distances. The Lissie and Willis are the principal source of water supply in the Houston area but contain salt water in Galveston County. The sands of the Lissie and Willis are the most heavily pumped in the region and the largest declines in artesian pressure have taken place in them.

The Alta Loma sand of Rose overlies the Lissie in the southern part of the region and consists of 100 to 300 feet of very permeable sand interbedded with a few thin layers of clay. The so-called Alta Loma is the principal aquifer in eastern Harris County and in Galveston County and, at Alta Loma, 20 miles northwest of Galveston, is the source of the water supply for the City of Galveston. The percentage of sand is much greater in the Alta Loma than in the Lissie and Willis formation.

The Beaumont clay, which overlies the so-called Alta Loma, has a maxi-

[2] Numbers in parentheses refer to References at end of paper.

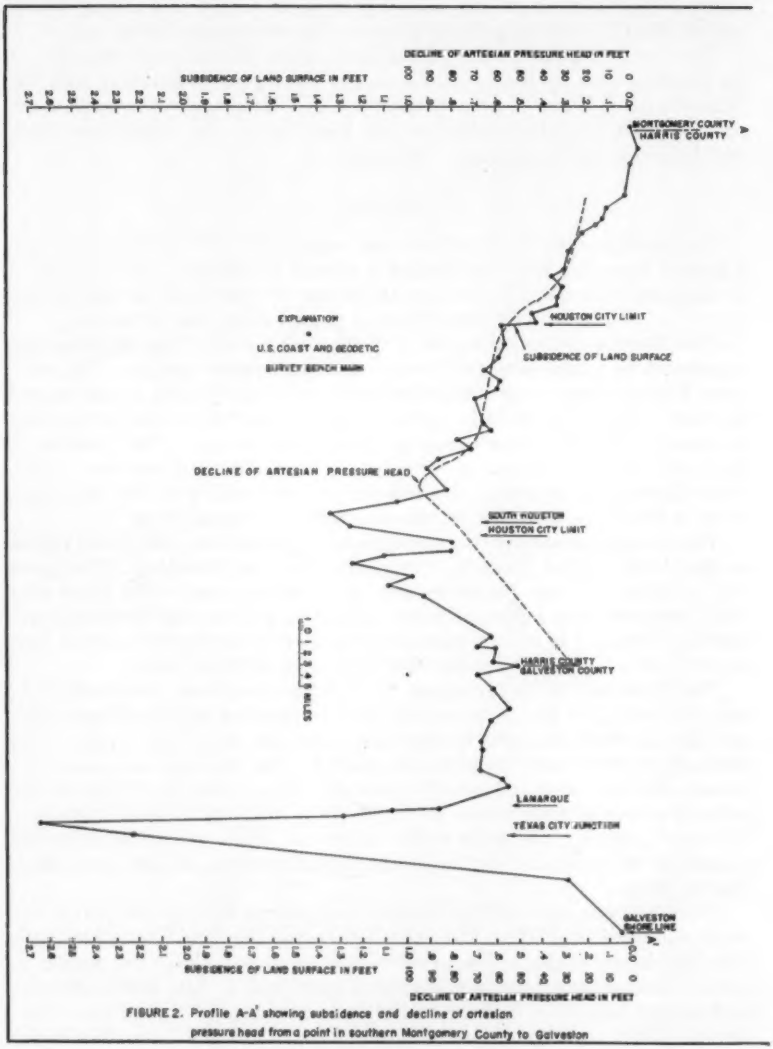

FIGURE 2. Profile A-A' showing subsidence and decline of artesian pressure head from a point in southern Montgomery County to Galveston

FIG. 2.

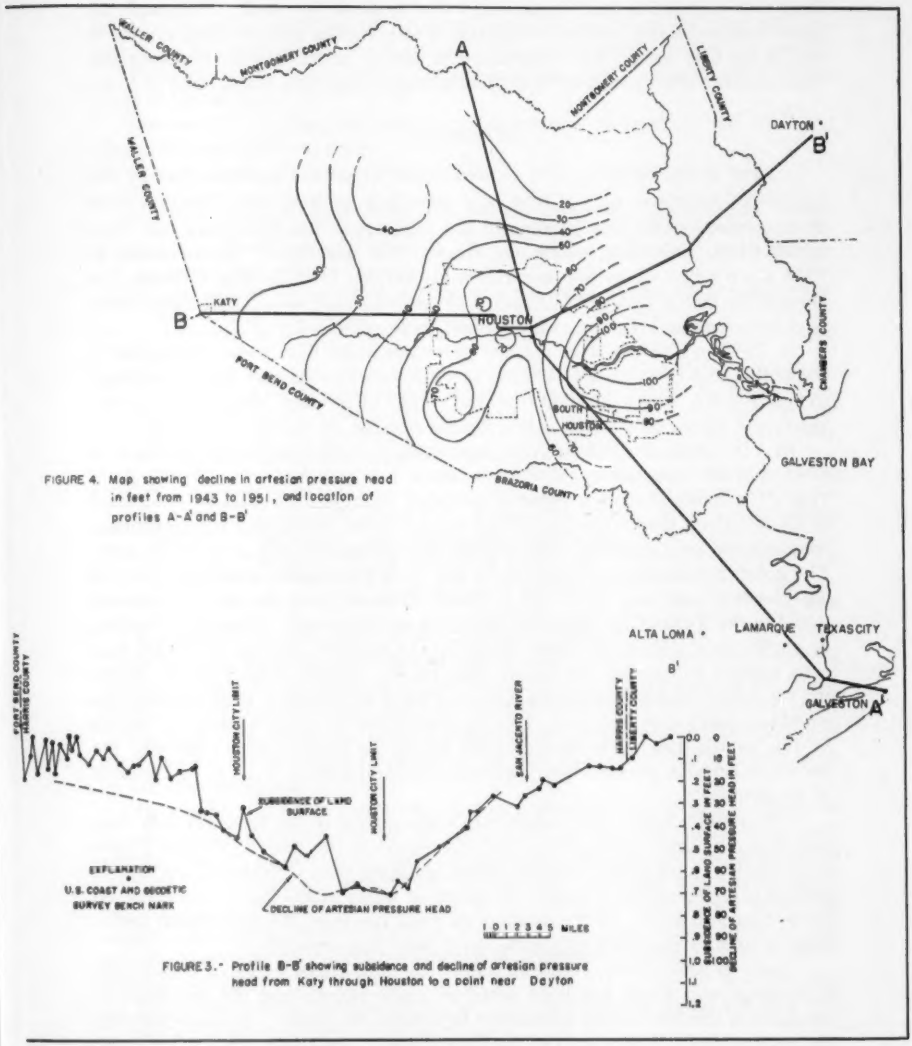

FIGURE 4. Map showing decline in artesian pressure head in feet from 1943 to 1951, and location of profiles A-A' and B-B'

FIGURE 3.- Profile B-B' showing subsidence and decline of artesian pressure head from Katy through Houston to a point near Dayton

FIGS. 3 AND 4

mum thickness of about 1,200 feet in southern Galveston County, and consists largely of calcareous clay containing a few beds of fine sand. Although the sands have relatively low permeabilities, they comprise the principal aquifer in the Texas City area. The percentage of sand is much less in the Beaumont than in either the Lissie and Willis formations or the Alta Loma sand of Rose.

SUBSIDENCE

Extent of Subsidence.—The United States Coast and Geodetic Survey has established extensive nets of first- and second-order level lines covering most of the region. The first leveling in the region was the first-order line from Smithville to Galveston, which was run in 1905 and 1906. The next was in 1918 when a first-order line was run from Sinton, Tex., to New Orleans, La. During the period between 1932 and 1936 several other first- and second-order lines were run and the two original lines were releveled.

In 1942 and 1943 a large number of second-order lines were established in the region and most of the old lines were releveled. At this time subsidence in the Houston area was noted from the results of leveling, although the actual amount of subsidence was not determined because of changes in datum.

In 1951 most of the first-order lines were releveled to the datum used in 1943, and the true nature of the subsidence became apparent. Profile A-A′ (fig. 2), extending from a point in southern Montgomery County southward to Houston and thence southeastward to Galveston, shows that the subsidence has occurred on a regional scale, though it is greatest in the Texas City area. The greatest subsidence discovered by the U. S. Coast and Geodetic Survey in the Houston area was 1.345 feet at South Houston, and the greatest amount found in the Texas City area was 2.641 feet at Lamarque. However, leveling by engineers at industrial plants about 2 miles east of Lamarque indicates that even greater subsidence has taken place there. Profile B-B′ (fig. 3) shows the subsidence along a line from Katy eastward to Houston, thence northeastward to a point near Dayton. The regional nature of the subsidence is shown by this profile also. The dashed lines shown on both profiles represent the decline in artesian pressure head between 1943 and 1951 in wells along the lines of the profiles.

Although probably more subsidence has occurred in the Houston area than was shown by the releveling, the local differences in the rate of settlement have been small. Consequently, few problems resulting from differential settlement, such as clogging of sewer lines or breaking of water mains, have been reported in the Houston area. In the Texas City area, however, the differential settlement is greater and such difficulties have been experienced.

Cause of Subsidence.—Subsidence of the land surface due to withdrawal of underground fluids has been noted in many places, and the processes of compaction involved in the subsidence have been discussed. Meinzer (4) has shown that part of the weight of the overburden is supported by the hydraulic pressure, and that a reduction in hydraulic pressure increases the load on the skeleton of the aquifer. He stated also (5) that the compression probably occurs largely in the finer-grained materials. As water is withdrawn, the hydro-

static pressure in the sands is reduced and a pressure difference is established between the clays and the sands, causing water to move from the clays into the sands. The weight of the overlying material causes compaction of the aquifer in proportion to the reduction in pressure head, most of the compaction taking place in the clays.

Tolman (9) discusses the effect of pressure relief on aquifers and confining formations and states in part:

> . . . .
>
> 2. If the aquifer is compressible and inelastic and yields to the weight thrown upon it by the relief of pressure, water originally stored in the pore space destroyed by the yielding of the aquifer is supplied to the well and reduction of pore space may be permanent. . . .
> 3. If the aquifer is overlain by impermeable clay or by a difficultly permeable formation, such as fine silt, water may be supplied to the aquifer by the reduction of pressure in the aquifer against the adjacent aquicludes under the following conditions:
>
> a. If the clay is not completely compacted by the weight of overlying formations, reduction of the pressure of the confined water in the aquifer on the confining strata will permit some of the water held in the clay to be squeezed out into the aquifer by the pressure of the overlying material and results in further compaction of the clay. Such compaction may be permanent.
> b. If the confining formation is slightly permeable, reduction of pressure in the aquifer will produce a hydraulic gradient from the confining stratum to the aquifer throughout the entire area of contact of aquifer and aquiclude within the area of influence. Slow movement of water out of the confining formation into the aquifer throughout the large area of contact may supply considerable water to the aquifer.
>
> . . . .

Tolman and Poland (10) in describing the land-surface subsidence in the Santa Clara Valley in California attribute the subsidence to the compaction of the clays following the removal of ground water. In a discussion of the subsidence of the Terminal Island area near Long Beach, Calif., Harris and Harlow (2) also give the removal of ground water as one of the factors contributing to the subsidence, although the removal of oil and gas has probably caused most of the subsidence (1).

In the Houston-Galveston region the withdrawal of large quantities of ground water probably caused the compaction of the clays and, to a much smaller degree, of the sands and, consequently, the land-surface subsidence. As the artesian pressure in the sands is lowered by pumping, a hydraulic gradient is established between the sands and adjacent clay beds. As a result, the water is drained from the clays and the artesian pressure which helps to support the weight of the overlying material is decreased, causing the clays, which are less competent than the sands, to be compacted. It may be assumed that the more deeply buried sediments are already partially compacted and that with increasing depth less compaction is possible.

The relation between the decline in artesian pressure and the land-surface subsidence in the Houston-Galveston region is shown on the profiles (Fig. 2–3). In the northern part of the region, where the fresh-water bearing formations are predominantly sand, the ratio between the subsidence of the land

surface and the decline of artesian pressure head is about 1 foot of subsidence to 100 feet of decline. In the southern part of the region, where the fresh-water-bearing formations contain a larger percentage of clay, the ratio is greater, indicating that subsidence may be ascribed principally to the compaction of the clays. The ratio of subsidence to the decline of artesian pressure head as shown by the profiles may not be the true ratio because of the presence of a time lag between a decline in artesian pressure and the corresponding surface subsidence. The time lag is introduced because of the slow rate at which water drains from the clays in response to a change in pressure (8).

The relation between subsidence and the withdrawal of ground water in the Houston-Galveston region is further complicated by the presence of many oil fields. The reduction of bottom-hole pressures following the removal of oil and gas and associated water probably causes compaction and subsidence in a manner similar to that caused by the withdrawal of fresh water. The depth from which the oil and gas is produced, however, would have an effect on the amount of subsidence possible, because the deeper the clays are, the more they are already compacted due to load and the less they can compact following a reduction in liquid or gas pressure. Pratt and Johnson (6) have described a land-surface subsidence of several feet in the Goose Creek field in eastern Harris County, following withdrawals of large quantities of oil and gas from shallow depths. They also state that Gaillard Peninsula, an area of considerable extent which had been used for grazing for many years, sank below the level of Galveston Bay after the development of the Goose Creek field. Although Pratt and Johnson ascribe the subsidence principally to the withdrawal of oil and gas, there was a considerable increase in the development of ground water in the area from 1917 to 1926. It seems reasonable to attribute part of the subsidence to the withdrawal of ground water.

The possible effect of oil fields on the subsidence is shown in the profile A-A′ (Fig. 2) at South Houston. It is at this point that the greatest amount of subsidence in the Houston area is recorded. This is probably associated with the withdrawal of oil and gas in the South Houston field, as well as the withdrawal of ground water in the region as a whole. From 1943 through 1951 approximately 22,000,000 barrels of oil and water, as well as an unknown amount of gas, were produced from the South Houston field. According to records of the Stanolind Oil and Gas Co. the average bottom-hole pressure in the field dropped about 356 pounds per square inch during the same period. This is equivalent to a drop in head of about 820 feet of water. Thus, at South Houston a relatively small amount of fluid has been produced, but the large pressure decline accompanying the production has probably caused a substantial part of the subsidence.

WATER RELEASED BY COMPACTION

The volume of water released by compaction of water-bearing materials in artesian aquifers is not always accounted for in ground-water studies. Tolman (9) in discussing ground water in the Livermore Valley, Calif., states ". . . This study indicates that where water levels have been similarly lowered by

over-pumping, water may be furnished by compaction of alluvial material in sufficient amounts to revise all prior estimates of specific yield and capacity of ground-water reservoirs and introduces a new factor in the ground-water inventory."

As the volume of subsidence is a measure of the amount of water released due to compaction, it is apparent that the quantity released in the Houston-Galveston region is of considerable importance. It is not possible to contour the subsidence in the region, and thereby compute the volume accurately, because the level lines in the vicinity of the Houston Ship Channel were not releveled during the 1951 leveling program. Figure 4, which shows the decline in artesian pressure head in the Houston and Pasadena areas from 1943 to 1951, indicates that the greatest decline in head took place in the vicinity of the Houston Ship Channel, and it is probable that the greatest amount of subsidence likewise took place in that area.

Although a precise determination of the volume of subsidence cannot be made, an approximation is possible. It is estimated that the volume was in the order of magnitude of 200,000 acre-feet, and that during the same period about 1,150,000 acre-feet of water was pumped. Inasmuch as the volume of water furnished by compaction must equal the volume of subsidence, it appears that approximately one-sixth of the water pumped during the period 1943 to 1951 has been supplied from storage, the remaining five-sixths having come from recharge in the outcrop areas. Short-term pumping tests indicate storage coefficients of 0.001 or less for the sands, indicating that 0.1 percent or less of the water pumped was taken from storage in the sands. The remainder of the approximately 17 percent must have been supplied from storage in the clays. It should be emphasized that the values given above are only approximations. It should be pointed out also that neither the effect of time lag between withdrawal of ground water and compaction nor the effect of the withdrawal of oil and gas has been included in these estimates.

SUMMARY

The releveling of 1951 shows a general land-surface subsidence of considerable magnitude in the Houston-Galveston region corresponding generally in area and depth to the cone of depression caused by the removal of ground water. The actual volume of the subsidence, and hence the volume of water released by compaction, cannot be computed accurately because level lines in the Houston Ship-Channel area were not releveled. If the amount of subsidence in the Ship-Channel area were determined, a reasonably accurate value for the total volume of subsidence in the region might be computed. However, 2 years has elapsed since the releveling of 1951, and additional subsidence has undoubtedly occurred. It might, therefore, be necessary to relevel the entire net in the region in order to obtain satisfactory ties to benchmarks in areas where there has been no subsidence. Inasmuch as a considerable part of the ground water withdrawn in the area appears to have been supplied by compaction, a periodic releveling throughout the region would be desirable. Correlating the data thus obtained with the geology and ground-water withdrawals in the re-

gion would result in a much better estimate of the over-all performance of the aquifer.

U. S. GEOLOGICAL SURVEY,
HOUSTON, TEX.,
Nov. 18, 1953

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VERTICAL ZONING AT THE O'BRIEN GOLD MINE, KEWAGAMA, QUEBEC

JOSEPH W. MILLS

ABSTRACT

A study of bullion assays and mine production records indicates a systematic variation in the purity of the gold recovered during the years 1936 to 1946. From 500 to 1,200 feet beneath the surface the ratio (gold: gold plus silver) × 1,000 increases from 860 to 920; below 1,200 feet the ratio is constant. Between surface and 500 feet the ratio is unexpectedly high (900–910); this is interpreted as possibly due to secondary enrichment.

The proportion of gold recovered by cyanidation as against that recovered by amalgamation during 1939–1946 has increased continuously suggesting that the particle size becomes smaller with depth.

INTRODUCTION

From time to time various authors have recorded changes in the mineralogy of Canadian Precambrian gold mines with depth; despite this the impression commonly gained from the literature is that the kinds and amounts of minerals are about the same at all depths in any one mine. That is, there is little evidence of any noticeable vertical zoning. Where careful quantitative work has been done, however, a vertical zoning of some type has been found to exist. For example, Auger (1)[1] has found a systematic variation with depth in the quantities of minor elements present in the associated sulphides of a number of Canadian gold mines.

From 1945 to 1950 the author was employed as resident geologist for O'Brien Gold Mines Ltd. at their producing mine in Northwestern Quebec, about 50 miles east of the Quebec-Ontario provincial boundary, on the Montreal-Val d'Or Highway. This term of office afforded ample time for a thorough acquaintance with the geology of the mine from 400 to 3,500 feet beneath the surface. The mineralogy is the same throughout; the proportion of certain minerals differs slightly in different veins but no change can be correlated with depth. A chance examination of bullion assays indicated a change in the proportion of silver alloyed with the gold with time. This suggested that a study of the purity of the gold produced over the years might show some systematic change as production came from greater and greater depths. This paper is the outcome of that study.

GENERAL GEOLOGY

For a more complete discussion of the regional and mine geology the reader is referred to papers by Mills (9) and Brown (2) and the bibliographies accompanying those papers.

[1] Numbers in parentheses refer to References at end of paper.

The vein host rocks are a series of isoclinally-folded, metamorphosed Precambrian graywacke, conglomerate, argillite tuff, andesite porphyry, and greenstone striking approximately east-west and dipping almost vertically. The gold-bearing veins are steeply-dipping tabular bodies of quartz transecting the rocks at a low angle with horizontal lengths of 1,000 feet or more and dip lengths as great as 3,500 feet. They are mineralized with arsenopyrite and minor amounts of pyrite, pyrrhotite, scheelite, calcite, tourmaline, and albite. The quartz is well fractured; the gold fills the fractures in the quartz and, to a much lesser extent, microscopic fractures in the arsenopyrite.

CHANGES IN GOLD: SILVER RATIO WITH DEPTH

Problem.—A study of the proportion of gold to silver won by amalgamation and cyanidation was made to determine whether, over a period of years, any change in the proportion could be correlated with increasing depths of production.

Method.—The total ounces of gold and total ounces of silver won during each three-month period were obtained from the official bullion assay returns of the Royal Canadian Mint at Ottawa. The proportion of gold to silver was recorded in the form (ounces of gold: ounces of gold plus ounces of silver) $\times$ 1,000 for the precious metal content of the gold bars produced by amalgamation, and for the total precious metals won by both amalgamation and cyanidation. This method of recording the proportion of gold present was preferred to the ratio gold: silver because the former gave three figure accuracy without introducing decimals and the figure is more likely to be significant to those readers who are accustomed to working with gold fineness. It is important to point out that the ratio used throughout is not synonymous with fineness. Gold fineness can be defined as the quantity of pure metal in alloys expressed by number of parts in one thousand. Other elements may be alloyed with the gold in addition to the silver. Actual fineness figures were not used in this study because in the process of liberating the gold from the rock and concentrating it, numerous impurities may be introduced into the finished bricks or bars to give a fineness which would not be representative of the fineness of the gold in its natural habitat.

Prior to the fiscal year 1936 all gold recovered was obtained by amalgamation and sulphide-rich concentrates were stock-piled. Since 1936 gold has been recovered by both amalgamation and cyanidation. During the years 1936, 1937 and 1938 the stock-pile concentrates were cyanided along with current production. For these reasons the proportion of gold to total precious metal in the amalgam bars can be compared from as early as 1935 but the proportion of gold to total precious metal in the combined amalgam and cyanide bars can compared only since 1938. Insufficient information is available for a comparison of the proportion of gold to total precious metal content of the cyanide bars alone.

An average depth figure was calculated in the following manner. Monthly working-place reports were examined to determine the number of ounces won from each stope, raise, and development heading, and the depth of such pro-

duction was obtained from mine sections. For each working place each month the product of ounces × depth was calculated. Over a three-month period the total ounces × depth figure was divided by the total ounces to obtain a figure for the average depth of production during that three-month period.

Results.—The proportion of gold to total precious metal content of the amalgam bars has been plotted against average depth in Figure 1. Each point

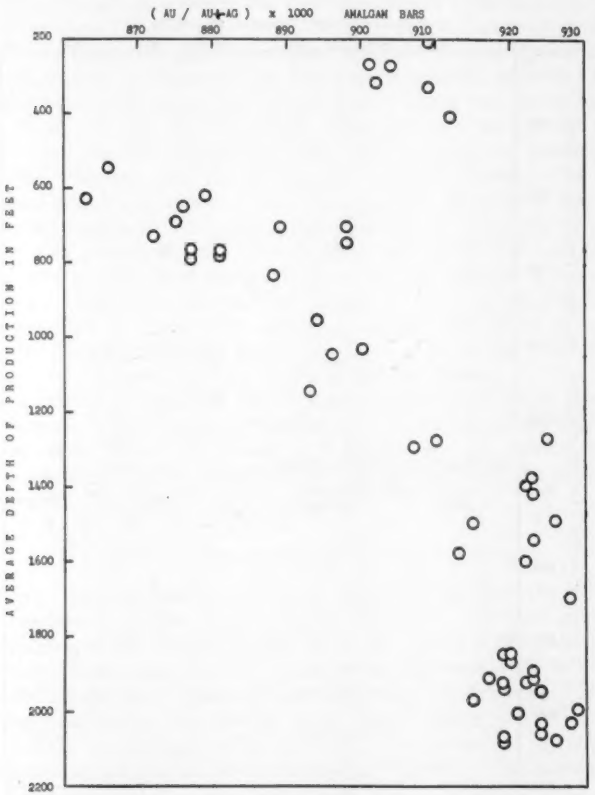

FIG. 1.

represents an average over a three-month period from 1935 to 1949 inclusive. Points could not be plotted for production since 1949 because the necessary information has not been available to the author. It can be seen from Figure 1 that in spite of a considerable spread in points plotted there is a marked general increase in the purity of the gold from 500 feet beneath the surface to about the 1,200 level. From the 1,200 level to an average depth of just over 2,100

feet the gold maintains a fairly uniform purity, which is greater than the purity at any lesser elevation.

Figure 1 also indicates that the purity of the gold won by amalgamation from above the 500 level is at least 40 parts per 1,000 higher than would be expected. It may be that this seemingly anomalous behaviour can be explained by an enrichment of the gold by circulating meteoric waters. This

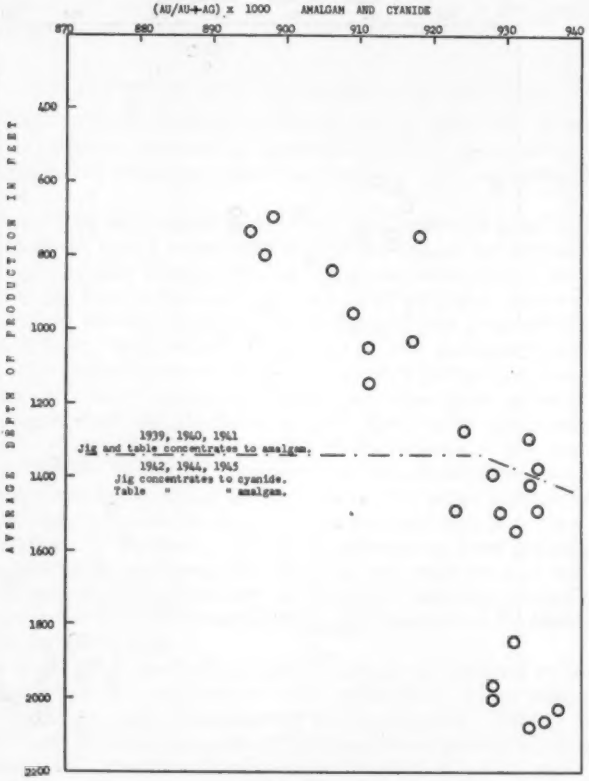

FIG. 2.

possibility is considered at greater length on the following pages. The higher ratio of Au : Ag may of course be the result of unknown hypogene environmental changes. N. H. Fisher (6) in discussing the fineness of New Guinea lode deposits, as well as deposits from other parts of the world, concludes that "fineness of gold shows a general increase with depth of deposition, which implies high temperature and pressure, and appears to be more closely correlated with

temperature." The change in gold fineness below the 500 level at the O'Brien mine conforms with this, but the gold above that level, if it is primary, does not conform. It is of interest to note that of the seven rather distinct orebodies above the 500 level, illustrated in Mills' (9) paper, only one is coextensive or continuous with orebodies below the 500 level. The other six terminate rather abruptly at or above the 500 level. It may be then that both the change in continuity of the ore and the change in purity of the gold are related in some way to unknown factors active at the time of hypogene mineralization.

The ratio of gold to gold plus silver for the total precious metal production from both amalgamation and cyanidation has been plotted against average depth of production in Figure 2. No data from production prior to 1939 was used because stock-pile concentrates from former years were being added to the mill circuit. During the years 1939, 1940 and 1941 the current concentrates from both the jigs and blanket tables were recovered by amalgamation. During 1942, 1944 and 1945 the concentrates from the blanket tables went to the amalgam and the jig concentrates to the cyanide. In spite of this change in the milling process it is believed that comparison of the purity of the gold during the two periods is permissible because we are dealing with the total ounces of gold and the total ounces of silver won by *both* amalgamation and cyanidation. Despite the fact that the number of points plotted in Figure 2 is much less than in Figure 1 it can readily be seen that there is a general tendency for the gold to become purer with depth as far as the 1,200 level and then to maintain a rather uniform purity at greater depths.

It is of interest to note that this increase in purity with depth is contrary to what Bruce (3) has reported as a result of a brief study of the ratio of gold to silver in a few Ontario and Quebec gold mines. His calculations, based on bullion assays through time, suggested that for some deposits the purity of the gold decreased with depth.

CHANGE IN GOLD PARTICLE SIZE WITH DEPTH

Gold recovered by amalgamation is generally coarser than the gold recovered by cyanidation so that the proportion of gold won by either process is a rough measure of the relative particle size. In Figure 3 the percentages of precious metals recovered by cyanidation during the years 1939 to 1946 have been plotted against the average depth of production for each year. The figure should be considered as two graphs, rather than a single graph, because the milling process was changed following 1941. The nature of the change has been indicated above and has been recorded on Figure 3. An examination of Figure 3 indicates that the percentage of gold and silver recovered by cyanidation has increased with time and depth. It is inferred then that the particle size of the gold (alloy) decreases continuously with depth.

GOLD PURITY IN DIFFERENT VEINS

By far the major proportion of the gold has been produced from three distinct veins, Nos. 1, 4 and 9, and minor branches from these (6). At different

times in the life of the mine, different proportions of the production have come from each of the veins. If the purity of the gold differed widely in the individual veins then the graphs of purity of gold from all veins would not present a true picture of the situation. In order to check this possibility the percentages of gold recovered from each of the three veins during three-month inter-

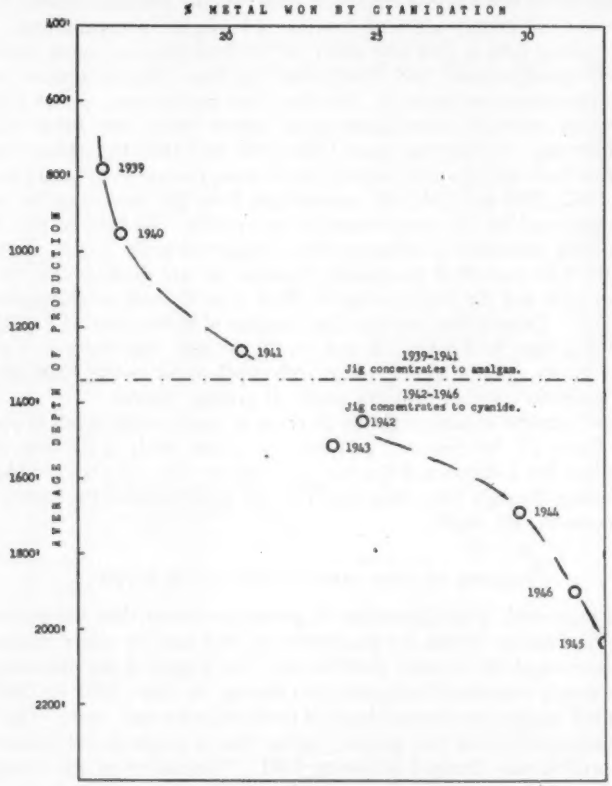

FIG. 3.

vals over the life of the mine were plotted on a triangular (equilateral) graph, the corners representing 100 percent production from each of the major veins, 1, 4 and 9. Beside each plotted point the ratio of gold to gold plus silver was indicated. The random distribution of points and gold ratios on this graph demonstrated conclusively that there is no correlation between purity of the gold and the vein from which it was recovered.

CONSIDERATION OF THE POSSIBILITY OF SUPERGENE ENRICHMENT

It was suggested earlier in this paper that the relatively high ratio of Au : Ag of the ore above the 500 level might be due to supergene processes. Analyses of bullion from 27 gold mines in Tanganyika and Nigeria led Mackay (8) to conclude "that coarse gold in the upper parts of an ore-body has a higher gold content than the finer particles in the same ore. It is believed that this is due to secondary enrichment processes, the gold formed by secondary enrichment having less silver than the primary gold of the same ore-body." Emmons (4) mentions a number of gold deposits displaying secondary enrichment of gold of higher than primary purity.

The problem arises as to whether such enrichment is due to solution and redeposition of gold or to a preferential leaching of silver from the alloy with a consequent increase in purity of the residual gold. Measured and predicted solubilities of gold have been made by many investigators and extensive references to the work have been given in papers by Emmons (4) and more recently by Smith (10) and Krauskopf (7). Although some of the results are contradictory it is well established now that the most likely natural means of solution transport of gold are as $AuCl_4^-$ in acid waters containing Cl^- and any one of the moderately strong oxidizing agents MnO_2, O_2, Fe^{+++}, Cu^{++}, or in dilute approximately neutral hot solutions of HS^-, or as alkali thioaurite in hot alkaline solutions. Since supergene waters are acid and at normal temperatures, it would appear that the first means of solution transport is the probable one. Krauskopf (7), from an analysis of thermodynamic data, concluded that such a process is a distinct possibility but he added that "the solubilities indicated are appreciable only under conditions which would be fairly uncommon in nature." Such conditions have been met, however, for Emmons (4) noted that in most recognized instances of supergene solution and enrichment of gold the deposits contained Mn. It does not appear that gold enrichment could have taken place by any such means at the O'Brien mine for no manganese-bearing minerals have been identified in the deposit and there is no indication that the wall rocks have been profoundly affected by circulating acid waters. It should be noted however, that the uppermost mine workings are largely inaccessible so that a final conclusion as to the rôle played by circulating acid waters cannot be made.

The possibility still exists that the alternate method of gold supergene enrichment may have been effective, that is, that the gold in the upper part of the mine has had some of its silver leached from the alloy by the action of meteoric waters, increasing its purity. It is commonly found that the placer gold farther downstream from the lode is of greater purity than the gold closer to the lode. P. S. Smith (11) states: "It has long been held that fineness bore a somewhat close relation to the distance that the gold had been transported from its source of origin. According to this belief, the gold in its original bedrock source is generally of relatively low fineness, but as the particles are worn, in the course of their transportation from that source, and are subjected to leaching by the natural soil acids and other processes, more and more of the impurities are removed so that the fineness increases." M. S. Fisher (5),

from investigations carried out mainly on a collection of samples of alluvial gold from the Morobe gold field of New Guinea, established that actually both gold and silver are dissolved by a sort of corrosion process, and that the gold is immediately reprecipitated as a film of fine gold on the surface of the nugget. N. H. Fisher (6), in a very comprehensive report on gold fineness of alluvial deposits of New Guinea, states: "Dr. Fisher's conclusions, derived from microscopical study, with regard to the origin of the gold in the Morobe field, are borne out in all general essentials by field observations." With regard to the lode deposits of New Guinea, N. H. Fisher (6) concludes that "gold in the oxidized zone is nearly always higher in grade than the primary gold, and this difference varies largely according to chemical conditions and the facilities that exist for removal of silver in solution, the gold being redeposited close by, or merely left enriched by the removal of silver."

CONCLUSIONS

a) The particle size of the gold recovered has become smaller with depth.

b) From about 500 to 1,200 feet beneath the surface the purity of the gold increased and at greater depths has maintained a fairly uniform purity.

c) Unusually high purity of the gold between 500 feet and surface suggests that there has been some secondary enrichment by preferential leaching of silver from the alloy by downward percolating meteoric waters.

ACKNOWLEDGMENTS

The writer wishes to thank the members of the mine staff, especially Mr. Basil Jackson and Mr. Ford Berry, who were most helpful in the interpretation of the mine and mill records. Thanks are also due Mr. Alan Scott, Mines Manager, who granted permission for publication.

DEPARTMENT OF GEOLOGY,
THE STATE COLLEGE OF WASHINGTON,
PULLMAN, WASHINGTON,
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EDITORIAL

SOME NEGLECTED FUNDAMENTAL PRACTICES OF ECONOMIC GEOLOGY

I do not remember exactly how, but some 35 years ago I obtained my first copy of ECONOMIC GEOLOGY. At that time I was a graduate of the School of Engineers of Lima, Peru, where I had received theoretical training inspired by the thinking of the Freiberg school. As I enthusiastically plunged into my first professional labors, the impact of reality upon theory was discouraging. Applied Geology, as it used to be called, was scarcely able to establish criteria for the classification of mineral deposits, and Agricola's theory of lateral secretion, defended fervently by Sandberger, was taught widely in the principal academic courses based on the works of German authors.

By then, however, the United States had entered vigorously into the first rank of mining countries, leaving behind most of the others, particularly in the production of fuels and many of the metallic minerals. Lindgren published the first edition of his great work "Mineral Deposits" in 1913, and a host of geologists and mining engineers who formed part of the great North American mining industry, or who carried out fundamental studies of ore deposits as members of government organizations, such as the United States Geological Survey, combined to establish new guides in the search for larger and more varied deposits.

The Journal of Economic Geology was formed by a distinguished group of these scientists in 1905, and began to make available to all members of the profession the new techniques aimed at attaining a high level of production. Fifteen years later, with the founding of the Society of Economic Geologists an additional stimulus was added. Inasmuch as the Journal has been devoted to the most advanced geological ideas and methods, I have been one of its most assiduous readers since first I became familiar with it. Although ECONOMIC GEOLOGY has been oriented in part toward practical ends, it has also been an outlet for articles of a purely scientific nature which have served as signposts pointing to new horizons.

Now that the Journal has completed nearly a half-century of publication, the question arises as to whether or not it is maintaining the leading position it has heretofore occupied. The prestige of ECONOMIC GEOLOGY is understandable when we consider that publication of new ideas by government entities is restricted to a considerable extent by a system of rigorous pre-publication criticism and that the mining industry often reserves for itself the fruits of its studies. Publications of independent institutions such as the Society of Economic Geologists enjoy the advantages of greater freedom, and above all of

offering opportunity for discussion. Of course, there must always be review and criticism, so that freedom to publish does not become a license for unbridled speculation, and so that due weight may be given to fact and opinion, respectively. However, new ideas in the science should ultimately be evaluated by institutions that not only are distinguished by their approval of and devotion to basic research, but also carry the endorsement of true freedom of investigation. The Society of Economic Geologists is one of these institutions and through its partnership with ECONOMIC GEOLOGY, the seemingly most penetrating studies and reports, both in the academic and the industrial fields, are given wide circulation. Nevertheless, what is published does not always include what is most needed by the profession. A few samples may illustrate my thesis.

Two general methods are available for the discovery of mineral deposits: horizontal or vertical exploration of the earth's crust. The evaluation of a virgin mineral deposit is not a simple matter, inasmuch as in most instances only small parts of the deposit are exposed and even these only rarely permit a reliable estimate of size. Deposits of valuable minerals are generally partly concealed by younger barren products of rock disintegration and erosion, although under certain favorable climatic conditions, for instance a glacial regime in which low temperatures combine with active mechanical weathering to produce fresh outcrops, ore deposits may be clearly and adequately exposed. Such conditions are met with in many places in the high latitudes or at high altitudes where the terrain is relatively free of ice or moraines. From a geomorphological point of view, the wealth of the lithosphere should best be exhibited in rugged mountainous areas subject to rigorous climatic conditions, because these areas offer the possibility of studying an unexplored ore deposit in three dimensions. The importance of favorable geomorphological conditions becomes evident when we consider the geographical distribution of productive mineralized areas throughout the world. These areas are concentrated largely in latitudes or altitudes of temperate climate. Although this distribution is in part due to economic or sociologic factors, it is due mainly to the fact that much of the tropical zone is covered by dense vegetation, and large areas in the polar latitudes or at high altitudes are covered by ice or glacial debris.

The Paley Report predicts that the present demand for minerals will be doubled by 1975. One is moved to ask what we know of the broad possibilities of finding enough new deposits to supply such a demand. It seems to me that geologists of the present century have already reconnoitered almost all the accessible regions in which mineral deposits, of commercial value because of size, grade, and proximity to centers of consumption, might be expected; we are left with areas remote from consumers, with concealed deposits, and with low-grade ores. Fortunately, centers of notable consumption are continually becoming more numerous and more widely scattered, so that deposits that had been considered unexploitable are no longer so, and will be less so in the future. Transportation facilities have been improved to such an extent that lowered costs allow mining operations in regions where they formerly

would have been inconceivable because of distance from fabricating centers. Finally, Nature herself is aiding the miner, as a world-wide deglaciation uncovers more and more land formerly buried under ice, and increasing aridity enlarges the more easily prospected desertic area. Improvements in mining and metallurgical techniques also make a valuable contribution to the problem of increasing mineral production.

Exploration in a vertical sense, on the other hand, has been extended and facilitated a great deal during the last few decades. The mining man of today utilizes the favorable condition of great topographic relief to estimate the probable persistence in depth of ore deposits, and he also has much improved methods available to predict conditions at depth not only because of the great development of geological, geophysical, and geochemical techniques but also because of technical improvements in exploration, drilling, and mining, which allow him to reach considerable depths in the earth's crust rapidly and at relatively low cost.

But with all these aids of Nature and technical improvements, it is doubtful that the mining industry would be able to keep pace with the world's population increase and the consequent increase, in part still potential, in demand for its products.

In the contest between tangential and radial search for mineral values in the lithosphere, man may well have gone too far in the first because of neglect of the second; we note that often mining companies, without having really gained a profound knowledge of their operating properties, will spend large sums of money in examination of new areas where the lack of knowledge of geological conditions increase the uncertainty of success.

The exploration of a new area is more costly than the exploration in depth of an already exploited region, except in the few cases in which, owing to profound dissection, the vertical continuity of ore to considerable depths may be ascertained almost at sight.

The most serious uncertainty facing the geologist who is confronted by the outcrop of a new ore deposit is the nature of its shape, dimensions, and physicochemical character at depth. In unexplored areas he can only guess, but his uncertainty becomes less when he notes any changes in character from place to place and compares them with those of known areas. This type of correlation is what the experienced geologist is paid for by industry, and it should become more and more a fundamental function of the profession and its methods given the widest possible diffusion.

By that reason, I believe that the overcautious elimination of economic data from geological reports for fear of compromising the sometimes obscure interests of the mining companies is against the highest aims of the science and mankind. I will always deplore also the mistaken attitudes of government organizations who at times are afraid that they will compromise the blind interests of the industry, and through this viewpoint actually aid in retarding that industry's development. The world needs more frankness and less fear and trembling to make its future more secure. Nothing could be farther from the truth than to state that the mineral resources of a region have been studied

when no information is given on tonnages and grades, the only data that allow us to evaluate the economic importance of a given deposit.

Inasmuch as human progress is a structure whose present is built on the foundation of the past, the dissemination of any knowledge whatsoever of the past, which might illuminate the future should not be suppressed. The historical data pertaining to a given ore deposit are at least as valuable as the data secured at the present time. Therefore, the systematic recording of structural data, and the reexamination of operating mines should be carried out continuously and with the greatest possible technical skill so that the future of a mine, or a district may be evaluated on the firmest possible basis. According to this viewpoint, it is worth insisting that, by means of a wider diffusion of the best scientific literature, the administration of the industry have at its disposal the technical capacity adequate to take full advantage of the advances being made continually in exploration methods, even though they may not be profitable at the moment.

I wish therefore to take this opportunity, in hoping for a bright future for the mining industry, to urge that:

1) A more scientific and economic attitude be taken toward the expansion of the minerals industry, in other words, that a more adequate geological technique be used in guiding mining capital to a clear discrimination between horizontal and vertical expansion of mineralized areas, and to a sharper judgment in determining the priority of one over the other when the satisfying of the needs of industry is concerned.

2) Less fear be felt that inclusion of economic data such as assays in reports will compromise the selfish interests of the industry. To exclude these data is to forget that the geologic study of the subsoil is aimed ultimately at serving mankind and to forbid their publication is to delay or lose forever the technical improvements that are indispensable for the future development of humanity.

3) The inestimable value of a history of geological environments encountered during a mining operation not be overlooked. A technical report on the history of a mine or district that presents only the production of valuable minerals in round numbers, without noting in detail the geological conditions under which the minerals were found, is of little value to later workers. Furthermore, reexamination of working deposits from time to time must be considered as a vital task of the profession.

I wish to thank Frank S. Simons of the U. S. Geological Survey, for his suggestions and for translation of this paper from the original Spanish.

J. A. Broggi

Instituto Geologico del Peru,
Lima, Peru,
Dec. 8, 1953

SCIENTIFIC COMMUNICATIONS

APHANITIC IGNEOUS ROCKS, A NEW SOURCE OF BLOATED LIGHTWEIGHT AGGREGATE

CHARLES M. RILEY

An ever-increasing demand by the building industry has stimulated an amazing advance in the production of the various forms of lightweight aggregate for concrete. At the present time there are three principal classes of raw materials: 1) cinders and vesiculated slag; 2) lightweight rocks such as pumice and diatomite; and 3) thermally expanded rock materials including clays, shales, slates, vermiculite, and perlite. It is with the third class that this report is concerned. Utilization of local materials is most desirable in any bulk building product, so that efforts have been made by manufacturers of lightweight aggregate to erect their plants as near to suitable markets as the availability of raw materials, fuels, and transportation will permit. Scarcity of suitable raw materials has been a deterent to the introduction of such industry in many parts of the country, particularly along the eastern seaboard. It is the purpose of this paper to demonstrate that many common widely distributed igneous rocks are suitable for the production of expanded lightweight aggregate.

Conley, Wilson, and Klinefelter (1)[1] analyzed and tested for bloating over 85 specimens of clays, shales, slates, and other rocks. The writer (4) plotted these data with six other analyses on a ternary composition diagram and was able to establish empirically a range of compositions suitable for bloating between 2000° and 2400° F. This showed that a certain balance of silica, alumina, and fluxing constituents is necessary so that a partial melt will form with a viscosity high enough to entrap the gases that are evolved at these temperatures. A silica or alumina content that is excessive requires fusion temperatures too high to be economically attained. A high percentage of fluxing constituents (CaO, MgO, FeO, K_2O, and Na_2O) results in a quick fusion to a melt with a viscosity too low to retain gas bubbles as they form. The proper balance of these constituents is expressed as an area on the composition diagram, which encircled all the points corresponding to rocks that bloated upon firing. It was noted (4) that many common igneous rock types have chemical compositions that fall within this area on the diagram. Several of these with phaneritic textures were tested. All of them bloated but only if they were first pulverized and cast into briquettes.

The earlier work described above suggested that the aphanitic equivalents of these rocks should bloat without earlier preparation, since nature has already

[1] Numbers in parentheses refer to References listed at end of paper.

supplied the necessary intimate mixture of minerals. Figure 1 shows the striking correspondence between the average compositions of these rock types as determined by Daly (2) and the area where the major oxide proportions are suitable for bloating. To test these conclusions fourteen rock samples of the species listed on Figure 1 were selected from the collections at the University of Nebraska. Petrographic studies were made from thin sections of each, and the bulk densities were measured using the Melcher technique of paraffin coatings (3). Small rock samples were then fired in an electric furnace to temperatures between 2150° and 2350° F, which with most of these rocks is high enough to produce bloating. In general seven to eight hours were required to bring the samples to the desired temperatures. Bulk densi-

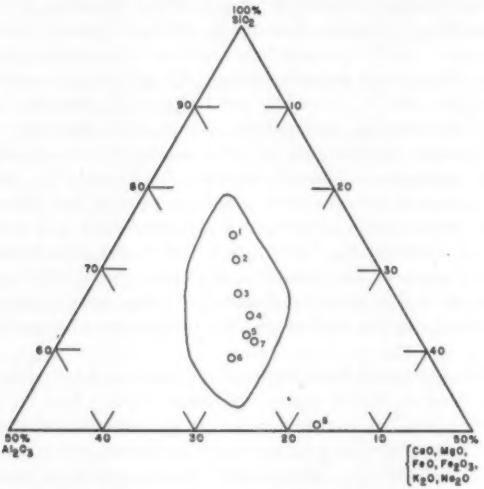

FIG. 1. Composition diagram of major oxides showing the area of compositions most suitable for bloating † in which are plotted the average compositions * of: 1) rhyolite, 2) granite, 3) dacite, 4) quartz latite, 5) trachyte, 6) phonolite, 7) andesite, 8) basalt.

ties were then determined for the fired specimens. The bulk densities before and after firing were compared to give a measure of the degree of bloating in terms of the percentage loss in weight for a unit volume of the rock. The percentage volume increase per unit weight was also computed. Table 1 summarizes the results of these tests. It should be noted that half of the rocks that bloated suffered a 50 percent or more weight loss per unit volume. Since it has been defined that a good lightweight aggregate should weigh less than half as much as the conventional aggregate it replaces (1), many of the samples expanded sufficiently for commercial use.

† Area of compositions suitable for bloating from Riley (4).
* Average compositions from Daly (2).

The writer does not wish to imply that any of these bloated rocks meet all the requirements for a good lightweight aggregate. In many instances a very sticky liquid phase formed during the firing. Although a good bloat was achieved, such material would be difficult to fire in a rotary kiln without taking precautions to prevent the formation of large clinkers that would clog the kiln. Some of the samples overbloated, resulting in pores so large that the strength of the aggregate is too low. Other properties required of a good aggregate such as low water absorption, or chemical inertness, were not evaluated in this limited study.

Although preliminary tests in a stationary furnace cannot accurately foretell the behavior of these rocks in a rotary kiln or a sintering furnace, they do show that with proper precautions many of the rocks could probably be used for lightweight aggregate. Since stickiness is the most common defect, it

TABLE 1

RESULTS OF FIRING TESTS ON VARIOUS IGNEOUS ROCKS

Specimen number	Rock name	Firing temperature °F	Bulk density* before firing	Bulk density after firing	% weight loss per unit volume	% volume increase per unit weight
1.	rhyolite	2335	2.371	1.175	50.44	101.78
2.	rhyolite (leopardite)	2310	2.542	2.031	20.10	25.17
3.	rhyolite porphyry	2335	2.384	1.078	54.78	121.13
4.	rhyolite tuff	2310	2.621	1.541	41.21	70.09
5.	fine grained granite	2310	2.616	1.707	34.75	53.24
6.	rhyolite obsidian	2220	2.348	0.692	70.54	239.26
7.	dacite porphyry	2335	2.469	1.434	41.92	72.19
8.	quartz latite porphyry	2310	2.670	1.549	41.98	72.38
9.	trachyte tuff	2335	2.261	1.084	51.96	108.66
10.	phonolite porphyry	2190	2.556	1.111	56.53	130.07
11.	andesite porphyry	2275	2.648	1.215	54.12	117.95
12.	andesite porphyry	2220	2.312	1.465	36.63	57.82
13.	basalt	2335	2.978	—	—	—
14.	basalt	2335	3.031	—	—	—

* Bulk density expressed in grams per cubic centimeter.

would seem that sintering might be the best method of bloating, using a refractory dust on the sintering grates. This same dusting technique might be used to coat the particles in a rotary kiln to prevent agglomeration. The overbloating could be corrected by lower temperatures and more rapid firing times. Of all the samples tested the rhyolite porphyry (Sample No. 3) seemed the best. It had over a 50 percent weight loss, yet gave a mass with pores no larger than 1 mm in diameter. The expanded material seemed to have adequate strength, and only a slight stickiness developed during the firing. Although the rhyolite obsidian (sample No. 6) overbloated to a grey pumice-like mass, the pores were very small so that lower temperatures and more rapid firing should give a useful product with greater strength and sufficiently low density. In general the rhyolites, trachytes, dacites, and quartz latite rocks gave more favorable results than the phonolite, andesites, and basalts. The latter group apparently are too rich in fluxing constituents which

cause them to melt too completely. In fact, the basalts fused quickly to a nonporous puddle.

Summary.—1. Previous work has shown that many acid and intermediate igneous rocks have chemical compositions with the proper proportions of silica, alumina, and fluxing constituents to produce a partial melt with a viscosity high enough to ensure good bloating at temperatures between 2050° and 2350° F.

2. The ability of these rocks to bloat depends upon their having an aphanitic or glassy texture in which the chemical or mineral constituents are intimately mixed.

3. Firing tests on rhyolites, trachytes, dacites, andesites, and others showed that most would expand sufficiently to give an aggregate light enough for commercial use.

DEPT. OF GEOLOGY,
UNIVERSITY OF NEBRASKA,
LINCOLN, NEBRASKA,
February 15, 1954

REFERENCES

1. Conley, J. E., Wilson, Hewitt, Klinefelter, T. A., et al., 1948, Production of lightweight concrete aggregates from clays, shales, slates, and other materials: U. S. Bur. Mines Repts. Invest. no. 4401.
2. Daly, R. A., 1933, Igneous Rocks and the Depths of the Earth, McGraw-Hill Book Co., Inc., New York.
3. Melcher, A. F., 1920, Determination of pore space of oil and gas sands: Mining and Metallurgy, no. 160, sec. 5.
4. Riley, C. M., 1951, Relation of chemical properties to the bloating of clays: Jour. Am. Ceram. Soc., vol. 34, no. 4, p. 121–28.

DISCUSSION

ORIGIN OF SOFT IRON ORES OF MICHIGAN—A REPLY

Sir: In a recent communication to this journal, Harold L. James rejects my conclusions regarding a hydrothermal origin for the soft iron ores of the Negaunee and Ironwood formations of Michigan. Much of the criticism by James is based on data that does not pertain to the areas under discussion (Marquette and Gogebic ranges); one criticism dismisses, without documented proof, longstanding observations by many geologists.

Mr. James dismisses the hydrothermal theory for soft ore development on the Marquette and Gogebic ranges because he does not accept it for the Iron River district. Such a conclusion is not sound. I know of no evidence that requires that all the ores of different districts must be of the same origin. Furthermore my original paper was not concerned with, nor did it consider, the Iron River district.

James suggests that the timing of ore development and vein emplacement on the Marquette and Gogebic would not permit the use of certain pyrite veins discussed by the present author as evidence for the hydrothermal theory. He bases the timing on an example in which the ore is earlier than a vein containing pitchblende. (James' preceding statement which implies the reverse of this timing was the result of a typographical error.—personal communication from H. L. James.) Regardless, the vein which James uses to support his conclusion is not from either the Marquette or the Gogebic ranges (Personal communication from L. P. Barrett), and hence it is not applicable to the problem. The pyrite veins, which are from the Marquette and Gogebic, were noted by the present writer to be associated with oxidation; they still stand as supplementary evidence for hydrothermal oxidation in the two ranges concerned. James also states, that, ". . . the soft ores themselves can definitely be established as having been formed before deposition of the sandstones of Cambrian age." This is an oft-repeated dogmatic statement which may or may not pertain to all the ore bodies of the various districts.

James accepts grunerite, the iron amphibole, as evidence for metamorphism, but he rejects the present author's (and Tyler's) interpretation that in the Negaunee and Ironwood formations, minnesotaite and stilpnomelane are metamorphic minerals. James cites their interbedding with siderite, chert, and the presence of greenalite in, ". . . the completely unmetamorphosed Gunflint iron-formation of Ontario . . ." as "virtual proof" that much of the minnesotaite and stilpnomelane are either of primary origin or are simply reorganized primary minerals. Whereas, in one sentence, he rejects the two silicates as metamorphic, in another sentence, he suggests they are metamorphic by stating: "But the soft ores are confined almost exclusively to areas of lower metamorphic grade, in which the principal silicates present are minnesotaite and stilpnomelane." (Before accepting James' statement that the Gunflint iron

formation is "completely unmetamorphosed," the interested reader should examine the section on regional and contact metamorphism of the Gunflint iron formation by J. E. Gill,[1] noting especially the textures and iron amphiboles (p. 707–8), in that iron formation developed as a consequence of metamorphism.)

James discusses a section of the original paper devoted to mineral changes noted in basic igneous rocks next to soft ores. He dismisses the hydrothermal interpretation given by the present author to four minerals commonly found in this altered wall rock for the following reasons:

1. "The chlorite and sericite have nothing to do with the processes of ore formation; they are products of regional low-grade metamorphism that predates the development of ore in the iron-formations." 2. Talc, " . . . may not be present at all . . . , " and 3. " . . . kaolinite, is abundant, . . . " but, " . . . is not critical."

The first reason offered by James rejects not only the interpretation suggested by the present writer for the wall rock alteration, but it also rejects the observation that next to ore, basic igneous (and other) rocks were altered to soapstone during ore formation. The correlation between ore and soapstone was so readily recognized by early workers that in 1892 Irving and Van Hise, reporting on a reconnaissance trip through the Gogebic, stated: (Mon. 19, p. 271), "One traveling along the iron range is at once struck by the constancy of the association of the iron ores and these so called soapstones." On the Marquette, W. S. Bailey expanded the observation by recognizing that the alteration of igneous rocks next to and in the ore bodies, as a consequence of the ore process, took many forms: such as from fresh rock to chlorite, from chlorite to other chlorites, soapstone, kaolin rocks, or talcose schists. He noted that many of these varieties were transitional one to another. In Monograph 52, Mead reported (p. 246–7) the results of a chemical and mineralogical evaluation of this alteration of basic igneous rocks which resulted from the ore forming process. He compared fresh rock away from ore where it contained no chlorite, no sericite, and no kaolin, with the same rock next to and in ore where it contained 63 percent chlorite, sericite, and kaolin. Such a development of chlorite, sericite, and kaolin, described by these competent observers as localized in the ore zone, is hardly "regional metamorphism."

James suggests that talc may not be present. Talc is present. The mineral has been identified (X-ray by S. W. Bailey, University of Wisconsin) IN the ore of the Tracy Mine, Marquette district.

Hence, until some proof is offered to the contrary, the mineral alterations in basic igneous rocks adjacent to the soft ore bodies in the Negaunee and Ironwood formations are still offered as evidence for hydrothermal oxidation.

VIRGIL I. MANN

DEPARTMENT OF GEOLOGY AND GEOGRAPHY,
UNIVERSITY OF NORTH CAROLINA,
CHAPEL HILL, NORTH CAROLINA,
Feb. 16, 1954

[1] Gill, J. E., 1927, Origin of the Gunflint iron bearing formation: ECON. GEOL., 22, p. 687–729.

REVIEWS

Les Gisements de Fer du Bassin Lorrain. By SIMONNE CAILLÈRE and FRANÇOIS KRAUT. Pp. 176; pls. 8; figs. 26. Mémoires du Muséum National d'Histoire Naturelle, Série C, Sciences de la Terre, Tome IV, fasc. 1, Paris, 1954.

The genesis of oolitic iron ores has excited considerable interest in recent years, both in the United States and abroad. Callière and Kraut, in a stimulating and well-documented report, have summarized and extended their long-continued studies of the mineralogical composition and texture of the iron ores of the Lorrain Basin, the famous "Minette" ores. They devote 107 pages to a systematic description of the mineralogy of the ore beds and intercalated sterile beds of each deposit in the Longwy-Briey and Nancy regions. Their final chapter sets forth a detailed and closely argued hypothesis of diagenetic origin in which oolites and gangue formed simultaneously at the same level in a viscous medium by a kind of differentiation.

Their methods involved polished sections, thin sections, differential thermal analyses, measurements of weight loss during heating for estimates of mineral percentage, and X-ray analyses for identification of silicates. The following noteworthy facts and generalizations were brought to light.

The ore beds of the Longwy-Briey region are significantly divisible into three parts. The lower beds are characterized by the abundance of siderite and silicates, the upper beds by predominance of iron hydroxides and calcite, and the middle beds by the coexistence of siderite, silicates, iron hydroxides, and calcite. Some pyrite and marcasite occur in the lower beds. Callière and Kraut generalize that the state of oxidation of the iron increases upward in the section, indicating that the water in the basin of deposition progressively changed from stagnant to aerated. Qualitative considerations of variations in relative abundance of some of the other elements suggest that the source of the iron was granodioritic rock that had undergone laterization in its upper part. In the Nancy region, which lies south of the Longwy-Briey region, the upper, middle, and lower beds lack mineralogical distinctiveness.

Well-crystallized magnetite occurs in four deposits in the Longwy-Briey region, mainly in the middle of the sequence. It replaces parts of fossil shells. In some places the magnetite is restricted to the gangue and to bits of gangue material that have served as nuclei of oolites; in other places it is as abundant in the bodies of the oolites as it is in the gangue. As a general rule the iron is more highly oxidized in the oolite than in the gangue.

The oolites consist of concentric layers of goethite surrounding a fossil, gangue, or detrital nucleus and enclosed by an enveiope of stilpnosiderite. Callière and Kraut define stilpnosiderite as more or less hydrated ferric "gel" whose optical properties are not characteristic, and which shows an endothermal reaction at 100° C. The iron in the gangue is better crystallized than that in the oolites.

Concerning the genesis of the ore, they comment that the idea that the oolites antedate the gangue (proposed by Bichelonne and Angot in 1939) cannot be maintained because bits of gangue act as nuclei for oolites and because unreplaced fossils are imprisoned impartially by oolites or gangue. Nor do they accept the idea of evolution of gel into goethite and hematite and then into magnetite. The presence of stilpnosiderite surrounding goethite rules against such a systematic evolution, as

does the appearance in fossils of each of the non-clastic minerals. Moreover, they believe it is impossible to assign definite relative ages to the different minerals, there being no evidence for the calcareous, silicate, and ferruginous periods proposed in 1909 by Cayeux. Instead, they believe the colloidal and crystalline material formed simultaneously, the colloidal material having moved in a viscous medium toward centers where it agglomerated into oolites, the crystalline material being left behind in the interspaces. The reader probably will wish for further explanation of the mechanics of this migration and agglomeration. That the medium was viscous is indicated by the occurrence of two or more oolites sharing a common outer rind and by various phenomena of indentation and intrusion.

Regardless of the broad scope of the title, the reader should not expect to find information on the mines of the Lorrain Basin, its reserves, or the sort of data useful for future computation of reserves. Nowhere in the report is there even a rough indication of the thickness of the individual ore beds or of the thickness of the iron-bearing sequence. The fact that the ore beds are Jurassic is buried in a discussion of provenance. The general geology of the Lorrain ores might have been summarized sufficiently to orient a grateful foreign reader at the sacrifice of very little space. One wonders at the recognition of iron gels of Jurassic age, in light of our experience with the rapid crystallization of artificially prepared iron gels. Most likely, the explanation is that Callière and Kraut have found no need to define the amorphous state as strictly as have such workers as Kulp and Trites.

With those minor qualifications, the detailed investigations and provocative hypothesis presented here are highly recommended to the general reader as well as to the specialist.

ROBERT J. DUNHAM

YALE UNIVERSITY,
NEW HAVEN, CONN.,
March 22, 1954

Sudbury Basin. By D. M. LEBOURDAIS. Pp. 210; figs. 20; 4 maps. The Ryerson Press, Toronto, 1953.

This is a story to be read by all interested in geology and mining and particularly by those also interested in nickel. It is not a text book, nor a geological report, but simply a story—a story of the history of the development of a mining center where some ninety percent of the world's nickel is produced today. It is a story of the early history, the physical problems overcome, the formation of great mining companies, the development of world uses of nickel, the foresight of individuals and the problems of war. Interwoven is some interesting geology, development of ore deposits and mining. There are life sketches of the individuals who played important parts in the development of the Sudbury Basin and a number of photographs of individuals and plants. For the general reader there is perhaps a little too much about the town of Sudbury itself, but this is forgiven because of the other interesting material telling of what makes a mining camp click.

The Bonanza Trail, Ghost Towns and Mining Camps of the West. By MURIEL SIBELL WOLLE (Illustrated by the Author). Pp. 476; 108 figs.; 14 maps. Indiana University Press, Bloomington, Indiana, 1953. Price, $8.50.

As a contemporary reference on the subject of ghost and near-ghost mining towns and camps of America, this book should interest many geologists, since it

treats the discovery, growth, development and abandonment of mining in twelve western states in human terms. Even though the book is written in a friendly, personal manner, the reader is provided with historical facts and provocation concerning the effects of the early sporadic and uncontrolled mining of the past century in America.

The personal commentaries and sketched drawings of the mining country and main streets of such famous camps as Elkhorn, Montana; Eureka, Utah; Jerome, Arizona; etc. have resulted from the author's personal travels through the western lode and placer territories, her private communications with the descendants of miners, and extensive library research into old records, books and newspapers.

While it is indicative from the lore that the early discoveries of gold were mainly accidental, the mining of silver and later, of copper, lead and zinc involved more controlled operations and development. Most mining towns, however, displayed a transitory life owing to the fluctuating gold and silver markets, the disappearance of ore veins, the accumulation of mine water, and the destruction of mills and smelters by fire. The consequences brought about huge shifts in populations with mine ownership and wealth amassed and lost in a relatively short period.

In tracing the paths of the pioneering prospectors the author has provided realistic accounts of the operations involved in the first Californian gold rush in 1849; the turquoise-mining of the Spaniards in New Mexico four centuries ago; and as the Mormons shunned mining for agriculture, the late discoveries of numerous metal deposits among the Utah Ranges by soldier-miners during and after the Civil War.

The book is complete with a glossary of mining terms, a bibliography by states, and an extensive index listing the various mines, mining districts, mills, smelters, mining and smelting companies.

VIRGINIA ROSS

BROWN UNIVERSITY,
PROVIDENCE, R. I.,
February 1, 1954

Leaders in American Science. First Edition. Pp. 852; 1400 photographs. Who's Who in American Education, Inc., 110 Seventh Avenue, North, Nashville, Tenn., 1953.

This newcomer in the biographical field is in a way a competitor to the long-established *American Men of Science*. It lists either by sketches or name, with or without pictures, some 13,500 leading scientists in higher education, business, industry, government, or private research. Some 1,400 photographs of individuals are included. A great many of the listings are merely name, address, and field of work, consisting of two or three lines only. This brevity, it is stated, is because of failure to receive requested data. If all listings consisted of biographical sketches, the volume would be several times the size of the present one.

Considerable emphasis is placed on the listing of 1300 scientists, selected by a poll of over 50,000 scientists. The resulting list was submitted for criticism to 200 members of the National Academy of Sciences, of whom over 100 gave it a thorough check. Other scientists also checked over the list resulting from the poll, and the final list occupies 30 pages listed under scientific fields. The publishers state that they do not claim that the list is perfect or that they have made no mistakes in such a poll. The first attempt is commendable. However, some of the omissions are rather striking, and some of the inclusions under the scientific fields

are rather peculiar. For example, in Geology, a sub-listing under "Geology Engineering" includes the name of Norman L. Bowen! (However, his name is also included under "Geology.") Also under "Geology, Economic" six names are included, one of which is T. Rankema, whereas the name of L. C. Graton is not included!

The pictures of the scientists are a help.

BOOKS RECEIVED

FRANK G. LESURE

Beryllium Resources of the Tin-Spodumene Belt, North Carolina. W. R. GRIFFITTS. Pp. 12; pls. 3; figs. 3; tbls. 4. U. S. Geological Survey Circ. 309, Washington, D. C., 1954.

California Journal of Mines and Geology, Vol. 50, No. 1. Pp. 285; pl. 1; figs. 63. California Department of Natural Resources, San Francisco, 1954. Price, $1.00. Contains: Annual Report of the State Mineralogist, by Olaf P. Jenkins; California Mineral Commodities in 1951, by Henry H. Symons and Fenelon F. Davis; Mines and Mineral Resources of Amador County, California, by Denton W. Carlson and William B. Clark. *This last paper discusses gold produced from Mother Lode Belt and from dredges and hydraulic mines. Clay, coal and copper also important.*

Missouri Geological Survey—Rolla, 1953–54.

Rept. of Inv. 14. Coal in Northeastern Carroll County and Southeastern Livingston County, Missouri. WALLACE B. HOWE and WALTER V. SEARIGHT. Pp. 8; pls. 1. *Reserves estimated as 1,693,000 tons in two coal beds, Croweburg and Bevier.*

Inf. Circ. 10. The Mineral Industry of Missouri in 1951. EUGENE S. SMITH. Pp. 19. *Production figures for mineral products, including lead, cement, coal, stone, lime and raw clay.*

North Dakota Geological Survey—Grand Forks, 1954.

Circ. 5. Well Data and Tops of Significant Wells. Pp. 111. *Includes list of wells for which samples are available.*

Rept. of Inv. 16. Stratigraphic Sections of the Mississippian System in North Dakota. SIDNEY B. ANDERSON. 2 sheets.

Exercises en Projection Stéréographique. CARL FAESSLER. Pp. 221–273; figs. 16. Université Laval Contr. 10, Québec, 1953. *Although the author admits that he has not studied all that has been written on stereographic projection since Ptolemy, he does present many stereographic rules not usually found in crystallographic manuals concerning forms of the triclinic system and the hexoctahedral class of the isometric system.*

Geologischen Bundesanstalt—Wien, 1953.

Jahrbuch, Jahrg. 1953, XCVI. Band, Heft 2. Pp. 194–372; figs. 9; tbls. 7.

Varhandlungen, Jahrg. 1953, Hefte 3 und 4. Pp. 161–267.

Comité Spécial du Katanga—Bruxelles, 1954.

Op. 21. Feuille Mokabe, Ed. 1952, Notices. Pp. 69.

Op. 22. Feuille Sampwe, Ed. 1952, Notices. Pp. 71. *Both of these publications give brief accounts of topography, geology, soils and vegetation. Discussion of triangulation and listing of co-ordinates. Each includes three maps, scale: 1:200,000, geologic, topographic and soil.*

Geologie—Berlin, 1953.

Jahrg. 2, Nr. 4. Pp. 229–302.

Jahrg. 2, Nr. 5. Pp. 303–398.

Beiheft Nr. 7. Über oberkarbonischer und devonische Ostracoden in Deutschland und in der Volksrepublik Polen. EGMONT KUMMEROW. Pp. 75; pls. 7.

Beiheft Nr. 8. Die isolierten Skelettelemente der Asteroidea (Asrerozoa) aus der obersenonen Schreibkreide von Rügen. ARNO HERMANN MÜLLER. Pp. 66; pls. 11; figs. 9; tbls. 8.

Geological Survey of Japan—Hisamoto-chō, Kawasaki, 1952–53.

List of Publications of the Geological Survey of Japan (1880–1952). Pp. 124.

Bull. Vol. 4, No. 10. Pp. 56. *Articles in Japanese, short English abstracts; include descriptions of copper ore in Ehime; recovery of cement copper in Iwate; molybdenite deposit in Gifu; magnetite deposit in Fukushima; and geophysical prospecting in Iwate and Ehime.*

New Zealand Geological Survey—Wellington, 1953.

Bull. 46. The Geology of the Dannevirke Subdivision. A. R. LILLIE. Pp. 156; pls. 10; figs. 36. Price, 37s. 6d. *Detailed account of stratigraphy, structure paleogeography and physiogeography of area. Economic products include bentonite and limestone.*

Bull. 52. The Geology of Wanganui Subdivision. C. A. FLEMING. Pp. 362; pls. 34; figs. 62; tbls. 50. Price, £3 10s. *Well illustrated, detailed study of physiography, structure and geologic history. Economic deposits include titaniferous magnetite sands, a potential source of iron, titanium and vanadium.*

Direcção Geral de Minas e Serviços Geológicos—Lisboa, 1949, 1951–53.

Estudos, Notas e Trabalhos, Vol. VII, Fasc. 3–4. Pp. 287–464; pls. 2; figs. 14. Contains: **Le Gisement de Fer de Guadramil by J. L. Guimarães dos Santos**—*description of iron ore deposits in Guadramil, composed of siderite and limonite;* **Estudo de Algumas Formações Calcarias dos Distritos de Vila Real, Viseu e Guarda by Artur Candido de Medeiros and Francesco Limpo de Faria**—*description of limestones of Vila Real district;* **A Ferraria da Foz de Alge, Periodo de José Bonifácio de Andrada e Silva (1802–1819) by J. Silva Carvalho**—*historical article about iron factory of Foz de Alge;* **Relatório do Serviço de Fomento Mineiro do ano de 1952 by J. L. Guimarães dos Santos**—*report on mineral production of Portugal for 1952.*

Catálogo, por ordem cronológica das publicações. Pp. 42. *Contains chronological list of publications of the Geological Survey of Portugal, 1865–1948, with supplement for 1949–1952.*

Comunicações, Tomo XXXII, 1. a parte. Pp. 302; pls. 64; figs. 25. *Contains 16 articles of general interest on pelontology, archeology, and geomorphology. Of economic interest are discussions of tin and tungsten deposits of Panasqueira and magnetite deposits of Vila Cova.*

Comunicações, Tomo XXXII, Suplemento. Carta Mineira de Portugal. Antonio Vianna. Pp. 2; pl. 1. *Mineral index map of Portugal, scale 1:1,500,000.*

Ministerio de Minas e Hidrocarburos—Caracas, 1953.

Revista de Hidrocarburos y Minas, Año IV, Num. 11. Pp. 133; pls. 33.

Revista de Hidrocarburos y Minas, Año IV, Num. 12. Pp. 158.

Actividades Petroleras, Año V, Nos. 110–111. Pp. 30.

SOCIETY OF ECONOMIC GEOLOGISTS

PRELIMINARY ANNOUNCEMENTS

Fall Meeting

The informal Fall Meeting of the Society of Economic Geologists will be held in Los Angeles, California, in conjunction with the Annual Meeting of the Geological Society of America and associated Societies November 1–3, 1954.

Although no formal sessions have been scheduled under S.E.G. auspices, contributions by members of this Society—or by others whose work lies within the general scope of the Society's activities—will be most welcome.

Field trips that should be of interest to members of S.E.G. have been scheduled as follows:

Death Valley and the Mojave Desert region—November 4–6
Ventura Basin and the Transverse Ranges—October 30–31
Eastern portion of the Los Angeles Basin—October 30
Southwestern portion of the Los Angeles Basin—October 31
Peninsular Ranges—November 4–5
Catalina Island—October 31
Northeastern Los Angeles Basin—November 2
Western Los Angeles Basin—November 3

Detailed information concerning these trips can be obtained through the Geological Society of America. Reservations should be made through this Society, and should be addressed directly to

Dr. William C. Putnam
Chairman, Annual Meeting, G.S.A.
Department of Geology
University of California
Los Angeles 24, California

All authors who plan to give papers at the Fall Meeting are urged to submit titles and abstracts as soon as possible to Arthur L. Howland, Chairman of the Program Committee, S.E.G., whose address is Department of Geology, Northwestern University, Evanston, Illinois. Closing date for receipt of abstracts in Evanston is July 15.

February Meeting

The Annual Meeting of the Society of Economic Geologists will be held in Chicago, Illinois, in conjunction with the A.I.M.E., in February 1955. Abstracts will be due in the hands of the Program Committee Chairman by October 1, 1954, and titles and abstracts should be received as far in advance of this date as possible.

THE PROGRAM COMMITTEE

SCIENTIFIC NOTES AND NEWS

WING G. AGNEW is chief of the U. S. Bureau of Mines, Region II, succeeding M. E. VOLIN. Mr. Agnew will supervise the bureau's activities in Washington, Oregon, Montana and Idaho from his office in Spokane, Washington.

SAMUEL KATZ, geophysicist at the Stanford Research Institute, has been awarded the 1953 George Frederick Kunz prize in geology and mineralogy. The award, given by the New York Academy of Sciences, was made for Mr. Katz' paper on "Seismic Study of Crustal Structure in Pennsylvania and New York."

WAYNE MACKENZIE is now a field geologist for the American Metals Company with his first assignment in New Brunswick, New Jersey.

THE INTERMOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS will hold its 5th Annual Field Conference tentatively on the 26th, 27th and 28th of August, 1954, starting from Price, Utah, and ending in Bryce Canyon National Park. Highlights of the field trip will be the Clear Creek gas field, and portions of the Wasatch Plateau, San Rafael Swell, Henry Mountains, and Aquarius and Kaiparowits Plateaus.

OLAF N. ROVE, Secretary of the Society of Economic Geologists, has resigned as Acting Assistant Chief Geologist of the Geologic Division of the U. S. Geological Survey to return to industry work. Mr. Rove has accepted an appointment with the Ore Division of Union Carbide and Carbon Corporation, 30 East 42nd Street, New York, in the administration of their foreign mineral field investigations. At the request of the Council, Mr. Rove will temporarily continue as Secretary of the Society. All regular and routine correspondence on Society affairs should continue to be sent to him, care of the U. S. Geological Survey, Washington 25, D. C., where Miss Martha B. Shanks will carry on Society affairs under the guidance of H. M. Bannerman as Acting Assistant Secretary. Personal and special matters pertaining to the Society can be addressed to Mr. Rove at his New York address. After Mr. Rove gets settled and established in his New York office, he will inform the Council as to his availability and willingness to continue (or not continue) as Secretary, contingent upon the limitations imposed by his new duties, and the wishes of the Council.

SAMUEL EPSTEIN of the Division of Geological Sciences at the California Institute of Technology has been promoted to associate professor of geochemistry by the Institute Board of Trustees. His promotion from senior research fellow is effective July 1. Dr. Epstein's more recent work has included paleo-temperature determinations and investigations of oxygen-isotope ratios in waters of various origins. He is currently investigating the isotopic compositions of the lighter elements in nature with reference to geological problems. He has previously held research positions with the National Research Council of Canada and the Institute for Nuclear Studies at the University of Chicago.

LLOYD A. THOMAS, geologist, is with Magma Copper Co., Superior, Arizona.

LEWIS L. HUELSDONK, general manager of Best Mines, Inc., Downieville, Calif., has been named to the California State Mining Board, to succeed WILLIAM WALLACE MEIN, JR., Calaveras Cement Co.

EILER L. HENRICKSON, assistant professor at Carleton College, Michigan, has received a $2200 grant for geological research from the Louis W. and Maud Hill Family Foundation. He will study the metamorphism of the Upper Huronian rocks.

EDWIN T. HODGE, Portland, Ore., has returned from his second tour of investigation in South Africa, Southwest Africa and Angola for Bethlehem Steel Co.

FREDERICK D. WRIGHT, research mining engineer, USBM, has left the Bureau on a six months leave of absence for Durango, Mexico, where he will have charge of the operations at the San Martin mine, near Sombrerete.

HORACE R. GRAHAM, president of Anglo-Lautaro Nitrate Co., was awarded the gold medal of the Chilean Institute of Mining Engineers at its annual convention held in Conception.

A. W. FAHRENWALD, head of the college of mines at the University of Idaho for 21 years will retire September 1st to do consulting work and engage in manufacturing.

K. A. DAVIES, lately Director of the Geological Survey of Uganda, has been bution to the geology of East Africa.
awarded the Murchison medal of the Geological Society of London, for his contributions to the geology of East Africa.

H. W. STRAKY, III, is at present geophysically investigating iron deposits in Northern Georgia.

THE SHELL FELLOWSHIP COMMITTEE on behalf of the Shell companies announces a 48 per cent increase in expenditures for fundamental research and fellowship programs for 1954–55. The increase will raise expenditures next year to $263,500 from the current year's $177,500. Grants for fundamental research are made to university departments to aid them in expanding research in their particular fields. A new feature was incorporated in the research grants for 1954–55, in recognition of the considerable contributions allied schools and departments make to the over-all accomplishments of a university's scientific departments. Each $5,000 grant designated for a specific science department will be supplemented by an unrestricted grant of $2,500 to be used by the schools as they see fit. The cost of the research grant program will rise from $70,000 to $142,500, a major part of the increase being due to the new provision described above. In addition the number of fundamental research grants will increase from 14 to 19. The fellowship program is designed to assist outstanding graduate students in obtaining advanced degrees. There will be 49 fellowships, one more than last year. The program cost will increase from $107,500 to $121,000.

Schools receiving research grants are: California Institute of Technology, Carnegie, Cornell, University of Chicago, Harvard, Massachusetts Institute of Technology, Northwestern, Notre Dame, Princeton, Rice Institute, University of Rochester, St. Louis University, Stanford, and Yale. The research grants are in the fields of chemistry, chemical engineering, geology, geophysical engineering, mechanical engineering, metallurgy-corrosion, physics and engineering mechanics.

The fellowships will aid students working in chemistry, chemical engineering, geology, geophysics, mechanical engineering, petroleum production engineering, physics, plant science, and business administration.

Shell makes no restrictions on the publication of research results nor on the way the funds are spent. It is intended that the funds be used to increase the amount of fundamental research carried on in the fields designated. Fellows are selected by their respective schools. Each fellow receives $1,500 for his personal use and his tuition and fees are paid. The schools receive an additional amount to cover fellows' research expenses. Candidates in their final year of doctorate study are given preference, but awards may be made by the schools to other graduate students. The fellows are under no obligation to Shell.

THE THIRD NATIONAL CLAY MINERALS CONFERENCE is to be held at the Rice Institute, Houston, Texas, October 27, 28 and 29, 1954, on the subject of Clay Mineral Technology. The Conference is sponsored by the Clay Minerals Committee of the National Research Council. A special part of the program will be devoted to fundamental or applied papers. Those interested in presenting papers in these or related fields are invited to notify A. F. Fredrickson, Washington University, St. Louis 5, Missouri, before July 15, 1954. All interested in the subject are cordially invited to attend the Conference.

ROBERT A. MACKAY, of Mackay and Schnellmann, London, has recently returned from Brazil where they are carrying out investigations in Minas Gerais.

THE WYOMING GEOLOGICAL ASSOCIATION will hold its Ninth Annual Field Conference July 30 and 31, 1954, with Registration July 29. It will include the Casper Area including Emigrant Gap Anticline, Alcova, South Glenrock, Big Muddy, Boone Dome, Notches, Poison Spider, Rattlesnake Mountain and West Poison Spider.

THE PACIFIC COAST REGIONAL CONFERENCE ON CLAYS AND CLAY TECHNOLOGY will consider clay-water systems at its meeting to be held at the University of California, Berkeley, on June 25 and 26. It is open to all interested in clays, petroleum, soil science, soil mechanics, geophysics and ceramics. Ten papers are scheduled. The cooperating agencies are divisions of the University of California, the Clay Minerals Committee of the National Research Council, the California State Division of Mines, Regional Office of U. S. Bureau of Mines, and the U. S. Geological Survey. Further information may be obtained from The Department of Conferences and Special Activities, University Extension, University of California, Berkeley 4, California.

THE NATIONAL SCIENCE FOUNDATION sponsored a Conference on Undergraduate Research in Chemistry held at Washington and Lee University, Lexington, Va., May 6–8, 1954. About 30 faculty members of representative colleges and universities attended the Conference to discuss the value of undergraduate research in encouraging able students to choose careers in chemistry and to continue graduate training toward advanced degrees.

ERRATUM: In the Discussion on the *Origin of Soft Iron Ores of Michigan* by Harold L. James that appeared in Volume 48, Number 8, the fourth line from the bottom, page 727, should read: "Actually, these minerals vein the soft ores *and* are clearly later on the basis of spatial relations."